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Horizontal functions concerned
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☐ Safety / Sécurité ☐ EMC / CEM ☐ Environment / Environnement ☐ Quality assurance / Assurance qualité

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Titre :

Title :

Maritime navigation and radiocommunication equipment and systems - Track control systems - Operational and performance requirements, methods of testing and required test results

Note d'introduction

Introductory note

This standard specifies the minimum operational and performance requirements, methods of testing and required test results for Track Control Systems defined by IMO in resolution MSC.74 (69) Annex 2. It also takes into account IMO resolution A.694(17) on general requirements, which is associated with IEC 60945.

Japan in their positive vote on the New Work Item proposal restated that this should be a joint ISO/IEC project. This was agreed at the IEC TC80 plenary in 1997. IEC are the lead.

ATTENTION Parallel IEC CDV/CENELEC Enquiry)	ATTENTION CDV soumis en parallèle au vote (CEI) et à l’enquête (CENELEC)

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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MARITIME NAVIGATION AND RADIOCOMMUNICATION EQUIPMENT AND SYSTEMS - TRACK CONTROL SYSTEMS

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FOREWORD

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International Standard IEC 62065 has been prepared by working group 1A, of IEC technical committee 80:

The text of this standard is based on the following documents:

FDIS	Report on voting
XX/XX/FDIS	XX/XX/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 3.

The committee has decided that the contents of this publication will remain unchanged until ______. At this date, the publication will be

- reconfirmed;
- withdrawn;
- replaced by a revised edition, or
- amended.

MARITIME NAVIGATION AND RADIOCOMMUNICATION EQUIPMENT AND SYSTEMS - TRACK CONTROL SYSTEMS

Operational and performance requirements methods of testing and required test results

1 Scope

This International Standard specifies the minimum operational and performance requirements, methods of testing and required test results conforming to performance standards adopted by the IMO in resolution MSC.74(69) Annex 2 Recommendations on Performance Standards for Track Control Systems. In addition it takes account of IMO resolution A.694 to which IEC 60945 is associated. When a requirement of this standard is different from IEC 60945, the requirement in this standard shall take precedence.

NOTE:All text of this standard, that is identical to that in IMO resolution MSC.74(69) Annex 2 are printed in *italics* and the resolution (abbreviated to - A2) and paragraph numbers are indicated in brackets i.e. (A2/3.3).

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 60945: *Maritime navigation and radio communication equipment and systems-General requirements-methods of testing and required test results*

IEC 61023, *Marine speed and distance measuring equipment (SDME); operational and performance requirements; methods of testing and required test results*

IEC 61075, *Loran C receivers for ships; minimum performance standards; methods of testing and required test results*

IEC 61108-1, *Global navigation satellite systems (GNSS) Part 1: Global positioning system (GPS) - Receiver equipment- Performance standards, methods of testing and required test results*

IEC 61108-2, *Maritime navigation and radio communication equipment and systems-Global navigation satellite systems (GNSS) Part 2: Global navigation satellite system (GLONASS) Receiver equipment - Performance standards, methods of testing and required test results*

IEC 61108-4, *Differential GNSS (under development)*

IEC 61162-1, *Maritime navigation and radio communication equipment and systems- Digital interfaces Part 1: Single talker and multiple listeners*

IEC 61162-2, *Maritime navigation and radio communication equipment and systems-Digital interfaces - Part 2: Single talker and multiple listeners; high speed transmission*

IEC 61924, *Integrated Navigation Systems (under development)*

ISO/IEC 11674, *Heading Control Systems (under development)*

ISO 8728, *Ships and marine technology-Marine gyro-compasses*

ISO 9000-1-4, *Quality management and quality assurance standards*

IMO Resolution A.694(17), *General requirements for shipborne radio equipment performing part of the GMDSS and for electronic navigational aids*

IMO Resolution A.830(19), *Code on alarms and indicators*

IMO MSC.64(67) Annex 3, *Recommendation on performance standards for heading control systems*

IMO MSC.74(69) Annex 2, *Recommendations on performance standards for Track control systems*

3 Definitions, abbreviations and symbols

For the purposes of this standard the following definitions and abbreviations apply.

3.1 Definitions

3.1.1
Active track
The track activated for track control

3.1.2
Alarm
Audio and visual signal announcing a condition requiring attention. The audio continues until acknowledged. The acoustic noise pressure of the alarm is at least 75 dBA but not greater than 85 dBA at a distance of 1 meter (IEC 60945). The visual indication continues until the alarm condition is removed.

3.1.3
Along track speed control
Automatic control of the ship's speed during track control based on a pre-planned track

3.1.4
Assisted turn
Manoeuvre of a ship from one straight leg to the next automatically controlled by a pre-set radius or rate of turn but not based on the ship's position

3.1.5
Back up navigator
Any individual, generally an officer, who has been designated by the ships master to be on call if assistance is needed on the bridge

3.1.6
Consistent common reference system:
Sensor input data, providing identical and obligatory reference pertaining to position, course, heading, bearing, speed, velocity etc. and horizontal datum to different sub-systems within an integrated navigation system

3.1.7
Course
For marine navigation, course is the horizontal direction in which a vessel is steered or intended to be steered, expressed as angular distance from north, usually 000° at north, clockwise through 360°.[1]

3.1.8
Course difference limit
Maximum difference between track course and heading before an alarm is activated

3.1.9
Cross track distance
Perpendicular distance of the ship from the track

3.1.10
Cross track limit
Maximum cross track distance before an alarm is activated

1 360° degrees is indicated as 000°.

3.1.11
Curved track
Non-straight track between two straight legs

3.1.12
Fall-back arrangements
Automatic reaction of the system to a failure to provide the best possible functionality

3.1.13
FROM-waypoint
The last passed waypoint

3.1.14
Great Circle sailing
Sailing on the intersection of the earth surface and a plane containing the points A, B and the centre of the sphere

3.1.15
Heading
The horizontal direction in which a ship actually points or heads at any instant, expressed in angular units from a reference direction, usually from 000° at the reference direction clockwise through 360°[2]

3.1.16
Heading control
Control of the ship's heading

3.1.17
***Heading monitor* function**
Monitoring the actual heading sensor by an independent second source

3.1.18
Indication
Visual display of any message to the user which may be accompanied by a low intensity acoustic signal to gain attention

3.1.19
Leg
A line between two waypoints defining the track

3.1.20
Main conning position
Place on the bridge with a commanding view providing the necessary information and equipment for the conning officer to carry out his functions

3.1.21
Minimum manoeuvring speed for track control
Lowest fore/aft speed through the water at which the track control system is capable of maintaining its performance within the specified accuracy limits. The value depends on the ship's design and loading and on the present environmental conditions.

3.1.22
NEXT-waypoint
The waypoint following the TO-waypoint

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2 360° is indicated as 000°.

3.1.23
Override facility
A control to perform the override function

3.1.24
Override function
An intentional fast change-over from automatic to temporary manual control

3.1.25
***Position monitor* function**
Monitoring the actual position sensor by an independent second source

3.1.26
Primary position-fixing system
Electronic position-fixing system (EPFS) used for track control and approved by the Organisation (see 4.1.1.3)

3.1.27
Radius of turn
Radius of a curved track

3.1.28
Rate of turn
Change of heading per time unit

3.1.29
Rhumb Line sailing
Sailing on a line on the surface of the earth making the same angle with the meridians

3.1.30
Ship manoeuvring characteristics
These define the range-of-manoeuvre possible for the ship (e.g., maximum turn rate, minimum turn radius, maximum turn acceleration and deceleration)

3.1.31
Single operator action
An action which is directly accessible and immediately effected, e.g. by:

- dedicated controls;
- primary access in an associated menu;
- alternative solutions which meet the functional requirements.

3.1.32
Speed
The absolute value of velocity. May either be the ship's speed through the water, or the speed made good over the ground.

3.1.33
Steering mode selector
A switch provided for the selection of manual steering modes and automatic steering devices.

3.1.34
Temporary track
A track that originates at the current position of the ship and joins the pre-planned track. The temporary track may include temporary waypoints which can be identified as different from the waypoints of the pre-planned track.

3.1.35
TO-waypoint
The waypoint which the ship is approaching

3.1.36
Track
Path to be followed over ground

3.1.37
Track control
Control of the ship's movement along a track, where corrections made by the controller to compensate for wind, drift and other influences, are based on the cross track distance and not only on the bearing to the destination waypoint (TO-waypoint)

3.1.38
Track course
The direction from one waypoint to the next, a constant course on a Rhumb Line track and a varying course on a Great Circle track

3.1.39
Track planning
Preplanning of track including waypoint data and optionally speed data, commonly referred to as passage planning or voyage planning

3.1.40
Waypoint
A geographic position together with its associated data

3.1.41
Wheel-over-line
The line where the ship has to initiate a curved track, taking into consideration the distance required for the ship to build up the necessary turn rate.

3.2 Abbreviations

~A	Not applicable for category A systems
CCA	Course change alarm
CCI	Course change indication
DR	Dead reckoning
ECCI	Early course change indication
ENC	Electronic navigational chart
EPFS	Electronic position fixing system
EUT	Equipment under test
GC	Great Circle
HSC	High speed craft
INS	Integrated navigation system
NA	(Back-up) Navigator alarm
RL	Rhumb Line
SDME	Speed and distance measuring equipment
WOT	Wheel-over time

4 Requirements and application of this standard

a) (A2/1)*Track control systems in conjunction with their sources of position, heading and speed information are intended to keep a ship automatically on a pre-planned track over ground under various conditions and within the limits related to the ship's manoeuvrability. A track control system may* (i.e. is not required) *additionally include* or be combined with

- *heading control*
- along-track speed control (see guidance in Annex B).

b) Planning the track by waypoints may be performed

- as part of the track control system or
- by importing waypoint or track data.

c) This standard applies for track control systems which can exchange data with a heading sensor, speed sensor, EPFS and/or heading controller but excludes waypoint data exchange.

d) If a track control system automatically receives additional data, including waypoints, from other navigational aids, the requirements of IEC 61924 for this data exchange shall also apply.

e) If a track control system is integrated into an INS, the corresponding requirements of INS (as defined in IEC 61924), e.g. concerning

- track planning by waypoints,
- data transfer of safety-checked waypoints and
- monitoring of navigational safety e.g. by charts

shall apply.

f) Track control does not necessarily require that ENC or other geographic data such as shallow area information be taken into consideration by the track control system.

g) (A2/2.1) *These Performance Standards are applicable for track control systems working*

- *at ship's speed from minimum manoeuvring speed up to 30 knots; and*
- *at ship's maximum rate of turn not greater than 10°/s.*

h) These performance standards do not apply to HSC as defined by SOLAS chapter 10.

i) (A2/2.2) *Track control systems fitted on ships* shall *meet all requirements of these Performance Standards relating to straight tracks. Systems fitted on ships requiring curved track control* shall *additionally meet all the requirements relating to curved tracks*.

j) This standard applies to three categories of track control systems:

Category A: Single straight leg track control or multiple straight leg track control without assisted turns between legs

Category B: Multiple straight leg track control with assisted turns between legs

Category C: Full track control on straight legs and turns

k) Some requirements contained in this clause cannot be verified by objective measurements. The manufacturer shall declare that compliance to these requirements is achieved and shall provide relevant documentation. The declaration(s), documentation and, where necessary, the equipment shall be checked. The manufacturer shall also declare the general hardware and functional composition of the equipment and the relevant category of IEC60945 for each unit.

4.1 Operational requirements

4.1.1 Functionality

4.1.1.1 Track control steering modes

(A2/5.1.1) *A track control system* shall *be able to steer the ship from its position*

.1 to a single waypoint; or

.2 along a track containing a sequence of waypoints

using Rhumb Line or Great Circle sailing*.*

4.1.1.2 Starting requirements

(A2/5.1.2) *The system* shall *allow the officer of the watch (user) to start or restart track control only if*

- the pre-planned track has been checked for plausibility and correctness of geometric and ship dependent limits before becoming the active track

and

- *the ship's position* relative to the selected track,
- *the difference between track course and actual heading,*
- *the ship's manoeuvrability,*

will result in a safe approach manoeuvre to the track. A safe approach manoeuvre is a planned manoeuvre which is within the manoeuvring characteristics of the vessel and which does not result in an unexpected turning direction.

For this purpose the system shall allow the user at least one of the following options

a) to select the TO-waypoint or a leg on a pre-planned track and to select the maximum allowable difference between the bearing to the TO-waypoint and the actual heading; or

b) to define a temporary track to go to the pre-planned track. The temporary track shall meet all ship manoeuvring characteristics which apply to a pre-planned track. (~A)

4.1.1.3 Primary position-fixing system

(A2/5.1.3) *The primary position-fixing system used for track control* shall *be an electronic position-fixing system (EPFS) approved by the Organisation.*

4.1.1.4 Position monitoring

(A2/5.1.4) T*he ship's position* shall *be continuously monitored by a second* or additional *independent position source.* [3] If the ship is fitted with a second EPFS and position is available from this EPFS its position shall be used for position monitoring. Otherwise, dead reckoning (DR) position shall be used as the second position source for position monitoring. The DR position shall be derived from a shipborne heading sensor and a speed and distance measuring equipment (SDME). Means shall be provided to adapt the acceptable deviation to the required steering accuracy. *This monitoring need not be an integral part of the track control system.*

4.1.1.5 Early course change indication (~A)

A graphical description of the sequences described here is given in Annex A.

(A2/5.1.5) *In the case of track control by a sequence of waypoints a* confirmable *'early course change indication'* shall *be given* up to 5 minutes, and *no later than 1* minute, *before the wheel-over line.*

The system shall *provide means for the officer of the watch* (user) *to confirm the* 'early *course change* indication' before *wheel-over*.

[3] E.g. a secondary GPS may be used to monitor a primary GPS.

4.1.1.6 Actual course change and confirmation (~A)

A graphical description of the sequences described here is given in Annex A.

a) (A2/5.1.6.1) *In the case of track control by a sequence of waypoints* and if the 'early course change indication' was confirmed a confirmable course change indication shall be given at between 30 seconds to 1 minute [4], at the earliest, before *the wheel-over line*.

If the 'early course change indication' has not been confirmed, a confirmable course change alarm shall be given between 1 minute [5] and no later than 30 seconds before the wheel-over line.

b) (A2/5.1.6.2) *The system* shall *provide means for the officer of the watch* (user) *to confirm* or acknowledge *the course change* indication or course change alarm at or before wheel-over.

c) (A2/5.1.6.3) *With or without the confirmation, the ship* shall *follow automatically the track*.

d) (A2/5.1.6.1)If the course change indication has not been confirmed by or *at wheel-over line* then *a* course change *alarm* shall *be given* instead.

e) (A2/5.1.6.4*) If the actual course change* indication or *the actual course change alarm is not confirmed by the officer of the watch* (user*) within 30 s* before or after the *wheel-over* line, *a back-up navigator alarm* shall *be given*.

4.1.1.7 Change of waypoints

(A2/5.1.7*) In the case of track control by a pre-planned sequence of waypoints, it* shall *not be possible to modify the TO-waypoint, the FROM-waypoint and* (~A) *the NEXT-waypoint* and their relevant associated waypoint data *while in the track control mode without creating a new track and until:*

a) *the pre-planning of the new track is completed; and*

b) *the starting requirements* (Section 4.1.1.2) *are fulfilled*.

4.1.1.8 Turn performance (~A)

(A2/5.1.8*) The track control* shall *enable the ship to sail from one leg to another by turns based:*

a) *on a preset turn radius; or*

b) *on a radius calculated on the base of a preset rate of turn* and the planned speed; and

within the turning capability of the ship.

4.1.1.9 Adaptation to steering characteristics

(A2/5.1.9) *The track control* shall *be capable of manual or automatic adjustment to different steering characteristics of the ship under various weather, speed and loading conditions*.

4.1.1.10 Permitted tolerance

The quality of the track control shall be such that overshoot, oscillation and constant track deviation are within tolerable limits both for straight and curved tracks.

(A2/5.1.10*) Means* shall *be incorporated to prevent unnecessary activation of the rudder due to normal yaw or sway motion,* sensor data resolution *and statistically scattered position errors.*

[4] There shall be as a minimum 15 seconds duration of the preceding indication before this indication is triggered.

[5] There shall be as a minimum 15 seconds duration of the preceding indication before this alarm is triggered

For systems which include great circle sailing, the calculated Great Circle approximation of the planned track shall not differ by more than 250 m from the mathematically correct solution based on Annex E.

4.1.1.11 Override function

(A2/5.1.11) A *track control system* shall *be able to accept a signal from the override facilities to terminate track control mode and switch to these override facilities*. After change over to override, return to track control shall require user intervention (see 4.1.1.2 Starting requirements).

4.1.1.12 Heading control mode

(A2/5.1.12) A *track control system may be operated in heading control mode. In this case the performance standards of heading control systems are to be applied.*

4.1.1.13 Manual change over from track control to manual steering

(A2/5.1.13.1) *Change over from track control to manual steering* shall *be possible at any rudder angle.*

(A2/5.1.13.2) *Change over from track control to manual steering* shall *be possible under any conditions, including any failure in the track control system.*

(A2/5.1.13.3) *After change over to manual control, return to automatic control* shall *require operator* (user*) intervention*. (see 5.3.5)

4.1.1.14 Manual change over from track control to heading control

This clause only applies if heading control is included in the track control system.

(A2/5.1.14.1) *Any change over from track control to heading control* shall *be possible under all conditions* of normal operation.

(A2/5.1.14.2) To maintain the course *the heading control system* shall *take over the actual heading as the preset heading*

(A2/5.1.14.3) *Any switching back to track control* shall *require operator* (user) *intervention*. (see 5.3.5)

4.1.1.15 Steering mode indication

(A2/5.1.15) *Adequate indication* shall *be provided to show which method of steering is in operation.* The indication of the steering mode is not required to be an integral part of the track control system, but shall be displayed at any work station of the track control system where the steering mode can be affected.

4.1.1.16 Heading monitoring

(A2/5.1.16)*Heading monitoring* shall *be provided to monitor the actual heading information by independent heading sources. The heading monitor is not required to be an integral part of the track control system.*

4.1.1.17 End of track

a) At the end of the pre-planned track, an 'end of track alarm' shall be generated.

b) Until the user takes over, the system shall follow the track course of the final leg. As a minimum, the system shall maintain the actual heading.

For category A systems the ‘end of track alarm’ shall be given at the end of each leg.

4.1.2 Accuracy and performance constraint documentation

(A2/5.2.1) *A short qualitative description of the effect of:*

.1 the accuracy of the sensors for position, heading and speed

.2 changes of course and speed;

.3 actual speed through the water; and

.4 environmental conditions

to the track control system shall *be provided to the user in appropriate documentation*.

4.1.3 Alarms and indications

All alarms and indications shall conform to the IMO code on alarms and indicators A.830(19). In addition, indications may be accompanied by a short low intensity acoustic signal.

4.1.3.1 Failure or reduction in power supply

(A2/5.3.1) *In case of failure or reduction of power supply to the track control system which effects its safe operation an alarm* shall *be given*.

4.1.3.2 Position monitoring alarm

(A2/5.3.2) *An alarm* shall *be given when the position monitor detects a deviation* between primary and secondary position-fixing system *beyond a preset limit*.

4.1.3.3 Heading monitoring alarm

(A2/5.3.3) *An alarm* shall *be given when the heading monitor detects a deviation beyond a preset limit.*

4.1.3.4 Failure and alarm status of sensor

(A2/5.3.4) *In the case of any failure or alarm status received from the position-fixing sensor, the heading sensor* or the speed sensor *in use:*

.1 an alarm shall *be generated at the track control system*;

.2 *the system* shall automatically *provide guidance to the user of a safe steering mode; and*

.3 *a back-up navigator alarm* shall *be given if a failure or alarm status is not acknowledged by the officer of the watch* (user) *within 30 seconds*.

Fall-back procedures consequential to the failure and alarm conditions are stated in section 4.5.

4.1.3.5 Use of faulty signals

(A2/5.3.5*) It* shall *not be possible to select any sensor signal tagged with a fault or alarm status.*

4.1.3.6 Cross track alarm

(A2/5.3.6) *A cross track alarm* [6], shall *be provided when the actual position deviates from the track beyond a preset cross track limit*.

4.1.3.7 Course difference alarm

(A2/5.3.7) A*n alarm* shall *be given if the actual heading of the ship deviates from the track course beyond a preset value.* The preset course difference limit shall be large enough to prevent unnecessary alarms.

4.1.3.8 Low speed alarm

(A2/5.3.8) *If speed through the water* in the fore/aft direction *is lower than a predefined limit necessary for steering the ship* under track control (minimum manoeuvring speed for track control) *an alarm* shall *be given.* This alarm is not required to be an integral part of the track control system.

4.1.3.9 End of track alarm

An alarm shall be given between 1 and 5 min before the last waypoint of the active track is passed. A back-up navigator alarm shall be given if the alarm is not acknowledged within 30 s.

4.1.3.10 Track control stopped alarm

A track control stopped alarm shall be given if the system automatically switches over to heading control or is unable to continue operation. A back-up navigator alarm shall be given if the alarm is not acknowledged within 30 s (see 4.5.1).

4.2 Ergonomic criteria

4.2.1 Operational controls

4.2.1.1 Controls for track control

(A2/6.1.1) *Means* shall *be provided to:*

.1 *accept or calculate the course between subsequent waypoints; and*

.2 *adjust radius or rate of turn, all* user settable *track control related limits*, limits for *alarm functions and other control parameters*.

Means may include but are not limited to a keyboard, knob or input at a screen.

(See restrictions under 4.1.1.7.)

4.2.1.2 Change over controls

(A2/6.1.2.1) *Track control to manual control*

Changing over from track control to manual steering shall *be possible by a single operator action*

(A2/6.1.2.2) *Track control to heading control*

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[6] Category B systems shall monitor assisted turns. The cross track deviation shall be measured at a minimum from the straight legs and cross track alarms shall be given during manoeuvres. If this monitoring is not done, the system shall be a category A system and track control must stop at the end of the leg.

If the track control system can be operated with a heading control system, changing over from track to heading control shall *be possible by a single operator action.*

(A2/6.1.2.3)*Location of change over controls*

The steering mode selector switch or override facility if installed shall *be located at or in the immediate vicinity of the main conning position.*

4.2.2 Presentation of information

4.2.2.1 Continuously displayed information

(A2/6.2.1) T*he following information* shall *be displayed clearly and continuously* in the vicinity of the main conning position; but not necessarily on a single display -*:*

.1 *mode of steering;*

.2 *sources of actual* selected *position, heading and speed*;

.3 status and failure of selected heading, speed, and position *sensors (if any)* and their related monitoring functions*;*

.4 track course and actual heading;

.5 actual position, cross track distance and speed over ground*;*

.6 TO-waypoint and NEXT-waypoint;

.7 time and distance to TO-waypoint;

.8 next track course;

.9 selected track identification; and

.10 optionally actual course over ground

For category B systems, an “assisted turn” indication shall be provided during course change manoeuvres.

Items .4, .5, .7 and .8 shall *be displayed numerically*.

4.2.2.2 Information to be provided on demand

(A2/6.2.2) *The following information* shall *be provided on demand:*

.1 a list of pre-planned waypoints including

- *waypoint numbers,*
- *co-ordinates,*
- *courses and distances between waypoints,*
- *turn radius or rates of turn* (~A)*;*

.2 all user settable *track control related limits and other preset control parameters*;

.3 geodetic datum in use.

The facility to provide the information in .1 is not required to be an integral part of the track control system.

4.2.2.3 Presentation

(A2/6.2.3)*Logically related values such as preset and actual values* shall *be displayed as a pair of data.*

4.3 Design and installation

The track control system shall be designed, manufactured and installed to approved international quality standards. [7]

4.4 Interfacing

Track control mode shall not be available unless required position and heading sensor data are valid and selected.

4.4.1 Sensors

(A2/7.1) *The track controller* shall *be connected to position, heading and speed sensors which meet the standards of the Organisation. The heading measurement system* shall *be a gyro-compass* or equivalent*.*

4.4.2 Status information

(A2/7.2) *All connected sensors* shall *be able to provide status, including failure information.* The track control system shall check for received status and failure information. If a sensor, used for track control, does not provide status or failure information, the track control system shall perform corresponding plausibility checks.

4.4.3 Standards

(A2/7.3) *The track control system* shall *be capable of digital, serial communication with the ships navigation system and comply with the relevant international standards.*[8]

4.5 Fall-back arrangements

The associated alarms are stated in section 4.1.3

4.5.1 Failure of track control

If track control fails a 'track control stopped' alarm shall be given.

(A2/8.1.1) *If the heading control is* installed and is *still available then the system* shall *automatically switch over to heading control and*

- if sailing on a straight leg *take the actual heading as the preset heading for the heading control,*
- if sailing on a curved path the turn shall be completed and the track course of the next straight leg shall be taken over as the preset heading (~A).

(A2/8.1.2) *If the heading control is not available the rudder angle* shall *be maintained,* i.e. stay in position*.* The rudder angle shall be set to a fixed angle such that:

- if sailing on a straight leg, the actual heading shall be maintained approximately;
- if sailing on a curved path, the actual rate of turn shall be maintained approximately (~A).

For advice on failure of track control mode when dual heading controllers are installed, see Annex C.

4.5.2 Failure of position sensor

If the primary position sensor has failed or is unavailable then:

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[7] ISO 9000

[8] IEC 61162

- the position sensor alarm shall be activated, and the track control system shall calculate the dead reckoning position of the ship;
- after 1 min another alarm shall be activated giving the advice to switch to a valid and available position sensor, heading control or manual steering. Even if acknowledged, this alarm shall be repeated every 2 minutes unless action is taken by the user;
- if no action has been taken after 10 min, the track control system shall automatically switch to heading control and a 'track control stopped' alarm shall be given. The system shall
  - if sailing on a straight leg take the actual heading as the preset heading,
  - if sailing on a curved path the turn shall be completed and the track course of the next straight leg shall be taken over as the preset heading (~A).

4.5.3 Failure of the heading measuring system

If the heading sensor fails, then

- the 'track control stopped' alarm shall be activated giving advice to the user to switch to manual control.
- (A2/8.2.1) T*he actual rudder angle* shall *be maintained* i.e. stay in position. The rudder angle shall be set to a fixed angle such that:
  - if sailing on a straight leg, the actual heading shall be maintained approximately;
  - if sailing on a curved path, the actual rate of turn shall be maintained approximately (~A).

4.5.4 Failure of the speed sensor

If the speed sensor fails or is unavailable then:

- the last plausible speed shall be used;
- an alarm shall be generated;
- the user shall be advised to switch to another speed sensor or if none is available to manual speed input.

5 Test requirements and results

All tests in this section are intended to be executed in a laboratory environment with a simulator. Additional onboard test may or may not be required.

5.1 General requirements

5.1.1 Environmental tests

5.1.1.1 General

All tests to the requirements of IEC 60945 shall be performed to verify that the EUT meets these technical requirements. The equipment shall comply with the requirements of IEC 60945 appropriate to its category or alternatively evidence of prior testing shall be supplied.

The manufacturer shall declare which equipment or units are 'protected' or 'exposed'. The manufacturer shall declare any 'preconditioning' required before environmental checks.

For the purpose of this standard, the following definitions shall apply for environmental tests:

Performance check

- A short functional check to show that the equipment under test is still operational without investigating all details of its functionality, e.g. power on equipment and activate any function.

Performance test

- A detailed test of the equipment covering all functions provided. A performance test shall ensure that the full functionality is available under the present environmental conditions, power supply and input/output conditions, e.g. satisfactorily performing a subset of scenario 3.

Inspection

- A visual check of the equipment or documentation.

5.1.1.2 Test site

Tests will normally be carried out at test sites, accredited by the type test authority. The manufacturer shall, unless otherwise agreed, set up the equipment and ensure that it is operating normally before type testing commences.

5.1.1.3 Identification of the equipment under test (EUT)

The IMO performance standards for track control systems do not require distinct hardware components supporting distinct functions. It is up to the manufacturer to perform the different tasks for track control in possibly different physical and logical parts of its system. This may result in different layout solutions for the

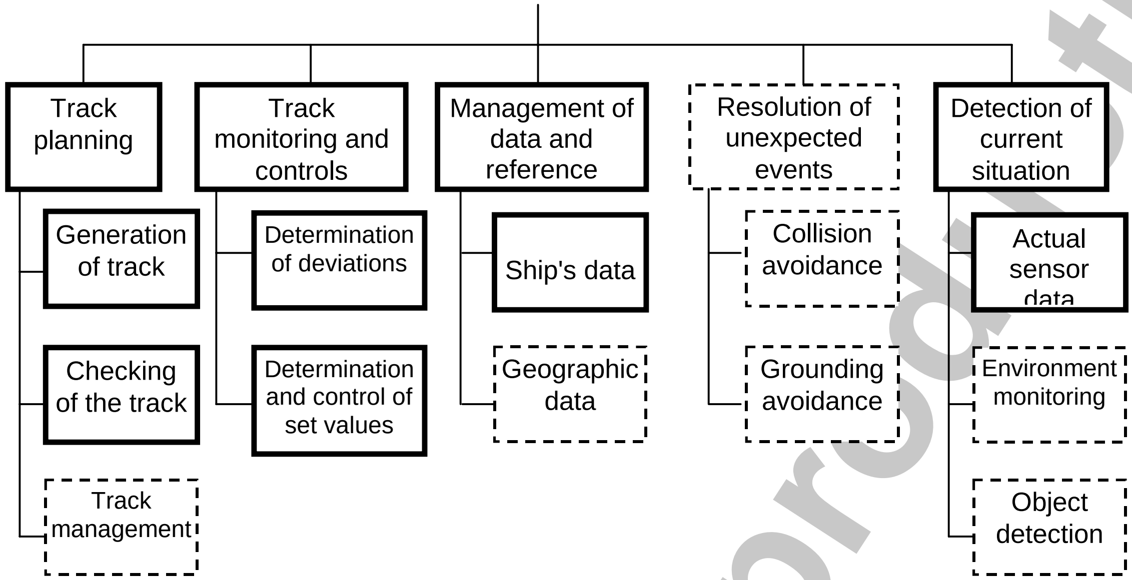
- physical parts involved,
- logical parts involved,
- general data flow between physical and/or logical parts,
- sensor interfaces,
- locations of required functions,
- user access (human machine interface).

Therefore the EUT's special layout and its information flow has to be identified before it can be decided which tests are applicable. Identification should follow a functional approach in steps:

a) Identify functions to perform different tasks of track control
b) Identify information flows between functions
c) Identify dependencies between functions
d) Identify in which parts of the system the required functions are performed

Identification of functions can be taken from the functional model of an integrated navigation system that incorporates track control (track control affected parts in boxes with solid lines).

Functional model of track control as part of an integrated navigation system



The information flow and the resulting dependencies between supported functions can be identified using the generic data flow diagram of the functional model (informative Annex F). A general scheme of the EUT´s components should be used to apply functions and their information flow to physical parts of the system.

5.1.1.4 Test of optional track control related modes

All track control related modes offered by the manufacturer shall be exercised.

5.1.2 Documentation

5.1.2.1 Equipment manuals

Verify that adequate information is provided to enable suitable qualified members of the ship's crew to operate and maintain the equipment properly.

5.1.2.2 Technical documentation for type approval

Manufacturers documentation shall include:

- Test certificate according to IEC 60945;
- Documentation of all system components and all relevant internal parts (parts lists, part numbers, drawings, pictures ...) according to IEC 60945 test certificates;
- Wiring diagrams of system components;
- Data flow diagrams of system components;
- Documentation of external interfaces available;
- Documentation of sensor data use, derived sensor data validity, ships parameters and reference parameters in physical and logical system components;
- Layout of the minimum system configuration and all other system configurations possible relevant to track control;
- Identification of relevant system components including names and numbers;
- Identification of relevant software revision numbers.
- Documentation specified by IEC 61162 series: "Digital Interfaces" for all relevant system components;

- Documentation of manufacturer test results based on this standard where appropriate.

5.1.3 Declarations

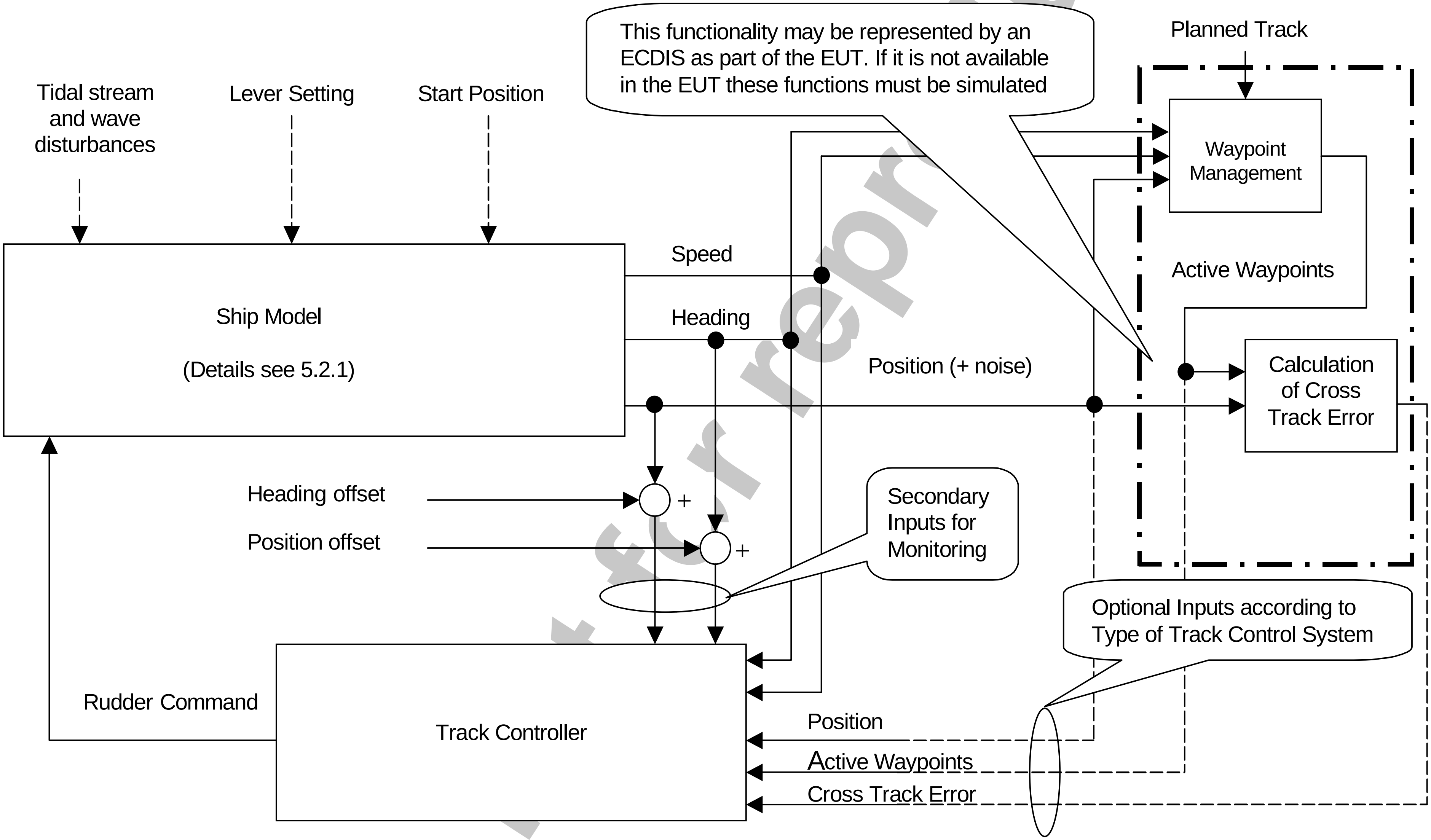
Some requirements cannot be verified by objective measurements.

Verify that

- the declaration and relevant documentation comply with the requirements in clause 4; and
- the general hardware and functional composition of the equipment and the relevant category of IEC60945 for each unit is declared. (See section 4)

5.2 Environment setup

Prepare the test environment (see block diagram next page) including necessary simulators and install the interfaces to the EUT. Verify that the 3 ship classes described below (5.2.1) are available in the simulator. Prepare the scenarios by loading the test tracks into the planning system which is used by the EUT.


This functionality may be represented by an ECDIS as part of the EUT. If it is not available in the EUT these functions must be simulated
Planned Track
Tidal stream and wave disturbances
Lever Setting
Start Position
Waypoint Management
Speed
Active Waypoints
Ship Model
(Details see 5.2.1)
Heading
Position (+ noise)
Calculation of Cross Track Error
Heading offset
+
Position offset
+
Secondary Inputs for Monitoring
Optional Inputs according to Type of Track Control System
Rudder Command
Track Controller
Position
Active Waypoints
Cross Track Error

5.2.1 Ship motion simulator

All functional tests of the track control system shall be performed using the ship motion simulator.

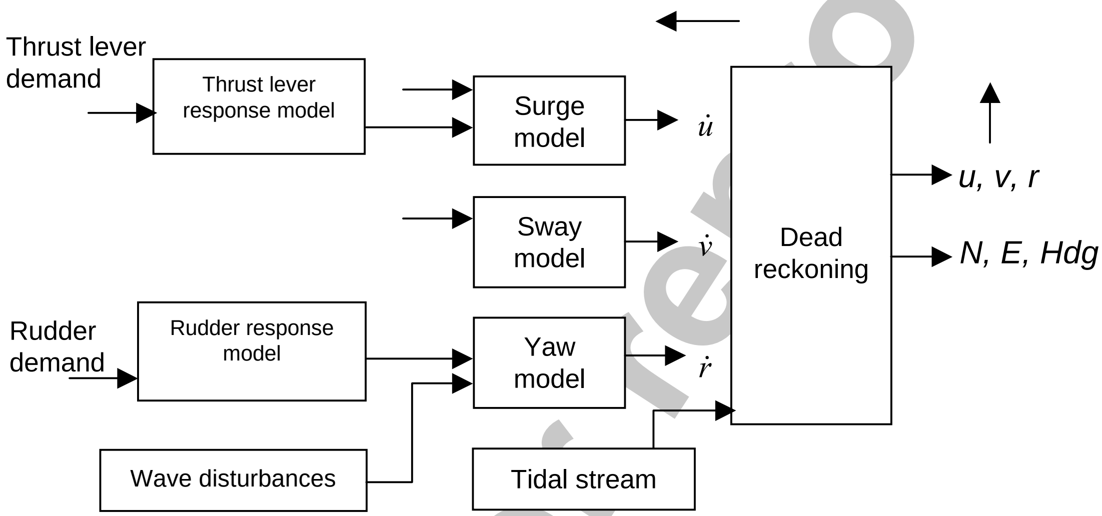
The ship's manoeuvrability shall be simulated in the range of

l/v = 5 (ship class A: 50 m / 20 knots, fast ferry, 8 m wide)

l/v = 20 (ship class B: 200 m / 20 knots, fast container ship, 32 m wide)

l/v = 60 (ship class C: 300 m / 10 knots, tanker, 40 m wide).

These ship classes shall be used during the test of the track control system together with the scenarios defined below.



The mathematical model of the ship motion simulator is based on linear relationships between motions, propulsor and rudder control inputs, and the forces acting on the vessel. The model may be set up using eight coefficients, all of which are related in a simple way to ship characteristics which are readily measured. One of the parameters is a stability coefficient which allows the model to be set up to exhibit straight-line instability. Parameter lists to generate three different types of ships and a detailed description of the simulator is given in Annex I.

The model shall accept data at a rate not less than specified below:

Input to simulator	
Demand RPM	Demanded rudder
1 Hz	10 Hz

The model shall update data and produce messages at a rate no less than specified below:

Output of simulator			
Position	Speed	Heading	Rudder feedback
1Hz	1 Hz	10 Hz	10 Hz

Additional simulation facilities for the following signals and functions shall be provided:

- position (second position source for monitoring, random noise model, failures),
- heading (second heading source for monitoring)
- steering mode selection, override tiller, alarm panel.

The noise model described in Annex H shall be used for the simulation position.

The resolution and accuracy of the simulated signals shall be in accordance with the applicable IMO, IEC and ISO requirements. The signal simulation shall use the interface standard as defined in IEC 61162. Any other types of interfaces (e.g. stepper or synchro, pulse log) shall also be tested.

5.2.2 Test Scenarios

The following test scenarios shall be used for the performance test of the track control system.

Scenario 1:

Complex Track at 0°N/0°E with ship class A (50 m/20 kt)

Scenario 2:

Complex Track at 0°N/180°E with ship class C (300 m/10 kt)

Scenario 3:

Zig-Zag Track at 65°N/0°E with ship class B (200 m/20 kt)

Scenario 4:

Rhumb Line / Great Circle Atlantic Track (Boston to Rotterdam) with ship class B (200 m/20 kt)

Details of the scenarios and graphs of the tracks are given in Annex G.

5.2.3 Planning

The defined test scenarios shall be created by the planning system used by the EUT and transferred to the EUT or stored.

5.2.3.1 Enter waypoints

Enter the waypoints of the test scenarios into the planning system. If necessary they may be entered or transferred into other parts of the EUT.

5.2.3.2 Enter additional data

Enter additional data (limits, control data, ship's parameters, etc.) as defined in the operating manual of the EUT.

5.2.3.3 Store

Store the planned data so that they may be recalled and activated during execution of the test scenarios.

5.3 Test execution

All tests concerning track control on curved tracks shall only be executed with systems able to perform this function. Systems without curved track control (Category A and B) shall be tested performing the course changes manually according to the manufacturer's documentation.

5.3.1 Check the track

Before any track becomes the active track, perform a check of the track data according to the operating manual of the EUT.

5.3.1.1 Check the radius (4.1.1.2) (~A)

The purpose of this test is to verify that the track control system recognises radius data that does not match the waypoint data (geometric check).

Method

Load the track data of scenario 1 and change or attempt to change the radius of waypoint 3 and 4 to 1.0 NM. Perform a check of the pre-planned track.

Result

Verify that indications are produced and that the changed track cannot be activated.

Restore the previous radius data and verify that no error messages are produced.

5.3.1.2 Check the waypoints (4.1.1.2, 4.1.1.7.2)

The purpose of this test is to verify that the track control system recognises erroneous waypoint data (geometric check).

Method

Load the track data of scenario 1 and move or attempt to move the position of waypoint 3 to the position of waypoint 1. Perform a check of the pre-planned track.

Result

Verify that indications are produced and that the changed track cannot be activated.

Restore the previous waypoint data and verify that no error messages are produced.

5.3.1.3 Check against the ship dynamics (4.1.1.2) (~A)

The purpose of this test is to verify that the track control system detects a track that cannot be steered based on the ship's manoeuvrability (dynamic check).

Method

a) Configure the track control system to use ship class C parameters. Load the data of scenario 1 into the system. Perform a check of the pre-planned track.
b) Change the radius of waypoint 2 and 3 to 1.0 NM.

Result

a, b) Verify that before or after activating track control, indications are produced that the track is not correct. Verify that no error messages are produced.

5.3.1.4 Invalidation of a modified track (4.1.1.7)

If the track control system has a facility to modify waypoints not included in the planning system or the planning system does not perform the check track function, this test applies.

Method

a) Change the radius of waypoint 8 in scenario 2 to 0.25 NM. (~A)

b) Repeat for any other methods of changing the track, including any facility to replace the active track.

Result

a, b) Verify that this modified track cannot become the active track in all cases.

5.3.1.5 Replace an active track without stopping track control (4.1.1.7)

If the track control system can replace the active track without stopping track control, this test applies.

Method

Place the ship's position between waypoint 6 and 7 of scenario 2 and activate track control.

Change a copy of scenario 2 by modifying the course between waypoints 6 and 7 so that the starting requirements are not fulfilled by the current ship's position.

Result

Verify that the system prevents the track copy from becoming active.

5.3.2 Execution of the scenarios

5.3.2.1 Start track control on the pre-planned track (4.1.1.2.1, 4.2.2)

This test only applies to systems that start track control directly, sailing on or near to the pre-planned track.

The purpose of this test is to verify that the track control system is able to activate a pre-planned track, to display the track related data, to reject or to accept the activated track and to activate track control, if accepted.

5.3.2.1.1 Display of data

Method

a) Load the track of scenario 1 and set up the simulator accordingly. Set the simulated position on the leg between the 1st and 2nd waypoint of the track. Set the ship's heading to 0° and the rudder to midships. Set the simulated speed according to the scenario.

b) Activate the pre-planned track.

Result

a, b) Verify that graphic displays, if available, show the ship sailing on the first leg heading towards waypoint 2. Verify that specified information to be displayed continuously or on demand is presented correctly.

5.3.2.1.2 "Start track control" not accepted

Method

a) Set the heading to the track course and the simulated ship's position so that the cross track difference to the track is beyond a preset limit.

b) Set the ship's position on the track and the simulated heading so that the course difference is beyond a preset limit.

c) If the EUT includes heading control, switch to heading control and repeat a).

Result

a, b, c) Verify with each of the methods that track control cannot be started and that the system gives an indication of the reason.

5.3.2.1.3 "Start track control" accepted

Method

Set the simulated ship's position and heading in order that

- the cross track difference to the track is below but close to the preset limit and
- the course difference is below but close to the preset limit.

Result

Verify that the system is accepting track control.

Verify that the track control system steers to the second waypoint. The system shall steer smoothly towards and then join the track.

5.3.2.1.4 Track modification (4.1.1.7)

Method

Attempt to modify the relevant data of the FROM-, TO- and (~A) NEXT-waypoint of the activated track during track control.

Result

Verify that this is not possible.

5.3.2.2 Start track control using a temporary track (4.1.1.2.2, 4.2.2) (~A)

This test only applies to systems able to generate a temporary track.

The purpose of this test is to verify that the system or the user is able to generate a temporary track, to display the track related data, to reject or to accept the temporary track and to start track control.

5.3.2.2.1 Start track control and display of data

Method

a) Load the track of scenario 1 and set up the simulator accordingly. Set the simulated position near but not on the track. Set the heading to 0 ° and the rudder to midships. Set the simulated speed according to the scenario.

b) Activate the pre-planned track.

c) Attempt to create a condition so that the temporary track does not fulfil the starting requirements and attempt to start track control.

d) If track control has not been started, start track control with a temporary track which does fulfil the starting requirements.

Result

a) Verify that the track control system or the user is able to generate a temporary track guiding to the pre-planned track. Verify that the system graphically displays the temporary track attaching to the pre-planned track. Verify that the temporary track can be accepted or rejected.

b) Verify that the specified information to be displayed continuously or on demand is presented correctly.

c) If this was successful, verify that track control cannot be started and the system gives an indication of the reason.

d) Verify that

- track control can be started and that the system accepts the temporary track;
- the system turns towards the track course of the temporary track and then follows it;
- the track control system steers to and joins the pre-planned track.

5.3.2.2.2 Temporary track modification (4.1.1.7)

Method

Attempt to modify the FROM, TO and NEXT waypoint of the temporary track during track control along the temporary track.

Result

Verify that this is not possible.

5.3.2.2.3 Pre-planned track modification (4.1.1.7)

Method

Proceed along the temporary track on to the pre-planned track. Attempt to modify the relevant data of the FROM, TO and NEXT waypoint of the activated pre-planned track during track control.

Result

Verify that this is not possible.

5.3.2.3 Execute track control under undisturbed conditions

The following clauses define the details of the tests to be executed with each scenario under operationally normal and undisturbed conditions.

5.3.2.3.1 Test using Scenario 1 (4.1.1.1, 4.2.2.1, 4.2.2.2)

The purpose of this test is to verify that the EUT is able to perform track control according to scenario 1 with ship class A and various turn rates/radii.

Method

Set the course difference limit to 15° and the cross track limit to 35 m. Load the track of scenario 1 and set up the simulator and EUT accordingly. Start the simulation at the beginning of the 1st leg of the track.

Start track control and let the system follow the track until the last waypoint is passed.

At the end of each leg confirm/acknowledge the course change indications and alarms within the assigned time windows. (~A)

Result

As the ship proceeds along the track, verify that

- the ship's actual course and position do not deviate from the pre-planned track beyond the preset limits;
- the graphic screens, if available, display the ship sailing on the track;
- the displayed information is presented correctly referencing the activated track and switch from leg to leg automatically;
- the course change indications/alarms are given as specified in 4.1.1.5, 4.1.1.6; (~A)
- at the end of the track the system proceeds as required under 4.1.1.17.

and if the system supports track control along curved tracks, verify that

- the track graphics include the curved tracks presenting the correct radii;
- the course changes are executed using the correct radii.

5.3.2.3.2 Test using scenario 2

The purpose of this test is to verify that the EUT is able to perform track control according to scenario 2 with ship class C and various turn rates/radii.

Method

Set the course difference limit to 15 ° and the cross track limit to 100 m**.** Set up the simulator and the EUT according to scenario 2. Start the simulation at the beginning of the first leg. Start track control and let the system follow the track until the last waypoint is passed. At the end of each leg confirm/acknowledge the course change indications and alarms within the assigned time windows. (see also 5.3.4.9) (~A)

Result

As the ship proceeds along the track, verify that

- the ship's actual course and position do not deviate from the pre-planned track beyond the preset limits;
- the graphic screens, if available, display the ship sailing on the track;
- the displayed information is presented correctly referencing the activated track and switch from leg to leg automatically;
- the course change indications/alarms are given as specified in 4.1.1.5, 4.1.1.6; (~A)
- at the end of the track the system proceeds as required under 4.1.1.17.

and if the system supports track control along curved tracks, verify that

- the track graphics include the curved tracks presenting the correct radii;
- the course changes are executed using the correct radii.

5.3.2.3.3 Test using Scenario 3

The purpose of this test is to verify that the EUT is able to perform track control according to scenario 3 with ship class B and various turn rates/radii.

Method

Set the course difference limit to 15° and the cross track limit to 60 m. Set up the simulator and the EUT according to scenario 3. Start the simulation at the beginning of the first leg. Start track control and let the system follow the track until the last waypoint is passed. At the end of each leg confirm/acknowledge the course change indications and alarms within the assigned time windows.

Result

As the ship proceeds along the track, verify that

- the ship's actual course and position do not deviate from the pre-planned track beyond the preset limits;
- the graphic screens, if available, display the ship sailing on the track;
- the displayed information is presented correctly referencing the activated track and switch from leg to leg automatically;
- the course change indications/alarms are given as specified in 4.1.1.5, 4.1.1.6; (~A)
- at the of the track the system proceeds as required under 4.1.1.17.

and if the system supports track control along curved tracks, verify that

- the track graphics include the curved tracks presenting the correct radii;
- the course changes are executed using the correct radii.

5.3.2.3.4 Test using scenario 4 Rhumb Line (RL)

The purpose of this test is to verify that the EUT is able to perform long term track control according to scenario 4 with ship class B in Rhumb Line (RL) mode.

Method

Set the course difference limit to 25° and the cross track limit to 200 m. Set up the simulator and the EUT according to scenario 4.

a) Start track control on the first leg in RL mode and let the system follow the track until waypoint 9 is passed. Confirm/acknowledge the course change indications and alarms within the assigned time windows. (~A)
b) Let the system follow the leg from waypoint 9 to waypoint 10 (this can be done unattended). Stop track control before or at waypoint 10.

Result

a) Verify
- the correctness of information on graphic displays, if available,
- the correctness of specified track related data during the test;
- that the course change indications/alarms are given as specified in 4.1.1.5, 4.1.1.6.(~A)

b) Verify by recording or observation that the ship proceeds from waypoint 9 to waypoint 10 along a constant track course with a cross track deviation not greater than 50 m.

5.3.2.3.5 Test using Scenario 4 Great Circle (GC)

This test is restricted to systems able to steer along a track in Great Circle (GC) mode.

The purpose of this test is to verify that the EUT is able to perform long term track control according to scenario 4 with ship class B in Great Circle mode and that the system is able to switch over from Rhumb Line to Great Circle mode and vice versa.

Method

Set the course difference limit to the maximum specified by the manufacturer and the cross track limit to 1000 m. Set up the simulator and the EUT according to scenario 4. Set the leg from waypoint 13 to waypoint 14 to Great Circle mode.

a) Start track control at the end of the leg from waypoint 12 to waypoint 13 in Rhumb Line mode and let the system follow the track until waypoint 13. If the system does not switch automatically to Great Circle mode, select Great Circle mode manually.

b) Continue Great Circle track control for a minimum of 4 hours.

c) Restart track control on the four Great Circle positions between waypoint 13 and waypoint 14.

d) Restart track control after setting the position before and the heading along the end of the Great Circle leg between waypoint 13 and waypoint 14 and let the system pass waypoint 14. If the system does not switch automatically to Rhumb Line mode, select Rhumb Line mode manually.

Result

a) Verify that

- the switch over from Rhumb Line to Great Circle is performed;
- the correctness of the graphic displays, if available;
- the indicated track related data during the test are correct.

b) Verify that

- the course changes while the ship is sailing on the Great Circle leg;
- the tested part of the leg is sailed on a Great Circle according to the calculated courses of scenario 4 without track deviations greater than the test cross track limit (by recording or observation).

c) Verify that

- the courses on the Great Circle approximation are correct.
- the calculated Great Circle approximation of the planned track does not differ more than 250 m from the mathematically correct solution based on Annex E.

d) Verify that

- the system is able to switch over from Great Circle to Rhumb Line mode automatically or manually after waypoint 14 has been passed;
- the tested part of the leg between waypoint 14 and waypoint 15 is sailed on a Rhumb Line according to the calculated course and with a cross track deviation not greater than 50 m.

5.3.3 Execution of additional tests

5.3.3.1 Adaptation (4.1.1.9)

The purpose of this test is to verify that the EUT is able to adapt by manual or automatic means to varying speed and weather conditions. Note that the performance of the above tests covers the verification of system capabilities for different loading conditions. For systems requiring preconditioning, provide sufficient adaptation to the ships model in use before the test scenarios are performed.

The effects of speed variations and weather conditions to be tested are:

- Influence of speed change during the turn
- Influence of current change on a straight leg
- Influence of current during the turn
- Influence of sea state during the turn
- Influence of sea state change on a straight leg

Method

Load the track of scenario 3 and set up the simulator accordingly.

5.3.3.1.1 Adaptation to intended speed change

a) Set the simulated ship on the first leg at a distance of 2 – 3 NM from WP2 sailing a course of 040° at 10 knots. Start track control. After the turn has been initiated, increase the commanded speed to 20 knots.

b) Restart track control on the second leg at a distance of 3 – 4 NM from WP3 sailing a course of 140° at 20 knots. After the turn has been initiated, decrease the commanded speed to 7 knots.

5.3.3.1.2 Adaptation to tide current change

c) Restart track control on the second leg sailing a course of 140° at 20 knots. When the simulated ship is 4 – 5 NM from WP3, induce a simulated tide current of 5 knots perpendicular to the track.

d) Restart track control on the first leg at a distance of 2 – 3 NM from WP2 sailing a course of 40° at 20 knots. In the middle of the turn induce a simulated tide current of 5 knots to North.

e) Restart track control on the second leg at a distance of 3 – 4 NM from WP3 sailing a course of 140° at 20 knots. In the middle of the turn induce a simulated tide current of 5 knots to North.

5.3.3.1.3 Adaptation to sea state

f) Restart track control on the first leg at a distance of 2 – 3 NM from WP2 sailing a course of 40° at 20 knots. Set the simulated sea state to 2 and complete the turn.

g) Restart track control on the second leg at a distance of 2 – 3 NM from WP3 sailing a course of 140° at 20 knots at sea state 2. In the middle of the leg induce a simulated sea state of 5.

5.3.3.1.4 Adaptation to loading conditions

h) Check that the manufacturer's documentation includes the method for adaptation to different loading conditions and exercise this method on one leg of scenario 3.

Result

a - h) Verify that the track control system is able to adapt to the varying conditions by automatic or manual means and that it follows the track without exceeding the cross track limit after the adaptation has been applied.

5.3.3.2 Rudder activity (4.1.1.10)

The purpose of this test is to verify that the EUT is able to prevent unnecessary activation of the rudder due to normal yaw motion, sensor data resolution and statistically scattered position errors.

Method

Load the track of scenario 3 and set up the simulator accordingly.

Set the simulated ship after waypoint 2 sailing a course of 140° with 20 knots.

Start track control and perform the following tests individually.

- Induce a periodical yaw motion using a sinus function with f = 0.1 Hz and an amplitude of +/- 4° into heading input of the track control.
- Induce the following reduced resolution sensor inputs, one at a time
  - heading 1/6°,
  - speed 1/2 kt,
  - position data 1/100 min (18 m).
- Induce statistically scattered position errors as per Annex H.

Result

Verify that the track control system is able to adapt to the disturbed environment by automatic or manual means and that it is following the track within the test track limit and without excessive activation of the rudder.

5.3.3.3 Ship steering bias (4.1.1.9)

The purpose of this test is to verify that the EUT is able to compensate for ship steering bias, such as asymmetries like hull flow and propeller effects.

Method

Load the track of scenario 3 and set up the simulator accordingly. Set the rudder offset to+2° simulating a steering bias. Set the simulated ship just after WP1 sailing a course of 040° at 15 knots. Start track control. Stop track control after 20 minutes.

Result

Verify by observation that the track control system is able to compensate for the ship steering bias.

5.3.4 Monitoring and alarms

All tests of operational alarms shall verify that these alarms, if acknowledged, remain as an indication while the alarm condition exists and comply with 4.1.3.

After each test in this section, re-establish normal operation conditions for EUT.

5.3.4.1 Failure or reduction in power supply (4.1.3.1)

This test may be combined with environmental tests in section 5.1.1

Method

a) Reduce the power supply of each component of the track control system successively below the limit specified by the manufacturer as the minimum for safe operation. In the absence of such data, limits according to IEC 60945 shall be used.

b) Switch off the power supply of each component of the track control system successively.

Result

a, b) Verify that an alarm is triggered by the track control system.

5.3.4.2 Position monitoring alarm (4.1.3.2)

Method

Supply a pair of position data to the position monitoring function (4.1.1.4) to be used with the track control system. Modify the primary data or secondary data in such a way that the positions differ from each other by greater than the preset alarm limit.

Result

Verify that a corresponding alarm is given.

5.3.4.3 Heading monitoring alarm (4.1.3.3)

This test applies only if the heading monitoring function is an integral part of the track control system.

Method

Supply a pair of heading data to the heading monitoring function (4.1.1.16) to be used with the track control system. Modify the primary or secondary heading in such a way that the headings differ from each other by greater than the preset alarm limit.

Result

Verify that a corresponding alarm is given.

5.3.4.4 Failure and alarm status of sensors (4.1.3.4, 4.4.2)

Method

Modify successively input data from the position-fixing sensor, the heading sensor and speed sensor in use for track control to simulate a sensor failure or an alarm status. If the EUT can accept position, heading or speed data from a sensor which does not provide status or failure information modify the input data to a non-plausible value.

Result

Verify that an alarm sequence and corresponding indications are generated as specified in 4.1.3.4.

(See also test of fallback procedures defined in 5.3.5.)

5.3.4.5 Use of faulty signals (4.1.3.5)

Method

Provide successively input data from the position-fixing sensor, the heading sensor, the speed sensor and any other sensor provided for track control in the system such that it is tagged with a failure status. Attempt to select the faulty sensor.

Result

Verify that it is not possible to select the sensor for track control purposes and a status indication is generated.

5.3.4.6 Cross track alarm (4.1.3.6)

Method

a) Modify the selected position such that a cross track distance is generated greater than the preset cross track alarm limit.
b) Acknowledge the alarm and modify the selected position such that the preset cross track alarm limit is not exceeded.

Result

a) Verify that a corresponding alarm is given.
b) Verify that the alarm status and its indication are cleared.

5.3.4.7 Course difference signal (4.1.3.7)

Method

a) Modify the selected heading input such that the preset course difference alarm limit is exceeded.
b) Acknowledge the alarm and modify the selected heading input such that the preset course difference alarm limit is not exceeded.

Result

a) Verify that a corresponding alarm is given.
b) Verify that the alarm status and its indication are cleared.

5.3.4.8 Low speed alarm (4.1.3.8)

This test applies only to systems in which the low speed alarm is an integral part of the EUT.

Method

a) Reduce the selected speed input below the minimum speed for track control.
b) Acknowledge the alarm and set the selected speed input to a value higher than the minimum speed for track control.

Result

a) Verify that a corresponding alarm is given.
b) Verify that the alarm status and its indication are cleared.

5.3.4.9 End of track alarm (4.1.3.9)

This test may be carried out simultaneously with other tests. (see 5.3.2.3)

Method

Follow a pre-planned track until the last waypoint is passed with and without acknowledging the 'end of track alarm' .

Result

Verify that corresponding alarms are given as described in 4.1.3.9.

5.3.4.10 Track control stopped alarm (4.1.3.10)

Each of these tests is to be carried out in track control mode.

Method

a) Create a failure condition other than sensor failures in the track control part of the system by any means which causes the system automatically to switch to heading control or renders it unable to continue in track control.
b) Disconnect the selected position input from the track control system or define it as invalid.
c) Disconnect the selected heading input from the track control system or define it as invalid.

Result

a, b, c) Verify that a track control stopped alarm is given after application of each method by the track control system itself or that an external alarm device is triggered by the track control system as described in 4.1.3.10.

5.3.4.11 Course change indications and alarms (4.1.1.5 and 4.1.1.6) (~A)

The purpose of the following sequence of tests is to fully exercise the course change indication and alarm conditions (see 4.1.1.5, 4.1.1.6 and Annex A).

The test shall be carried out using scenario 2.

After each test normal operating conditions shall be re-established. Irrespective of any alarm sequence the pre-planned track shall be maintained.

Method and result

5.3.4.11.1 First leg under test.

With no confirmations of indications and no acknowledgements of alarms verify that:

a) ECCI occurs between WOT - 5 minutes and WOT - 1 minute.
b) CCA occurs at between WOT – 1 minute and WOT - 30 seconds latest.
c) NA is triggered at WOT + 30 seconds.

5.3.4.11.2 Second leg under test.

Confirm ECCI before WOT - 30 seconds, verify that:-

a) CCI occurs at WOT - 30 seconds latest, do not confirm.
b) CCA occurs at WOT, acknowledge before WOT+ 30 seconds.
c) NA is not triggered.

5.3.4.11.3 Third leg under test.

Confirm ECCI before WOT - 30 seconds, verify that:-

a) CCI occurs at WOT - 30 seconds latest, confirm before WOT.

b) CCA does not start and NA is not triggered.

5.3.4.11.4 Fourth leg under test.

Do not confirm ECCI and verify that:

a) CCA starts at WOT - 30 seconds latest.
b) Acknowledge CCA before WOT + 30 seconds.
c) NA is not triggered.

5.3.4.11.5 Fifth leg under test.

Confirm ECCI at once after it occurred and verify that:

a) CCI starts at WOT - 30 seconds latest, do not confirm.
b) CCA starts at WOT, acknowledge.
c) NA is not triggered.

5.3.4.11.6 Sixth leg under test.

Confirm ECCI before WOT - 30 seconds and verify that:

a) CCI starts at WOT - 30 seconds latest, do not confirm.
b) CCA starts at WOT do not acknowledge.
c) NA is triggered at WOT + 30 seconds.

5.3.5 Fallback and manual change over

5.3.5.1 Failure of track control (4.5.1)

If a physically separated heading controller is included, these tests shall be repeated with and without failure of heading control.

Method

a) Select scenario 3 and start track control. Wait until the ship is proceeding steadily on a straight leg and create a failure condition other than sensor failures that renders the track control system inoperative.
b) Select scenario 3 and start track control. Wait until the ship is performing a course change manoeuvre and then switch off the power supply of the track control system or render it inoperative by any other means.

Result

a, b) Verify that the system reacts as specified in 4.5.1.

5.3.5.2 Failure of position sensor (4.5.2)

Select scenario 3 and start track control. Wait until the ship is proceeding steadily on a straight leg and perform these tests.

Restart track control using scenario 3 and repeat the tests during a course change manoeuvre. (~A)

Method

a) Switch off the selected position.
b) Tag the selected position input as invalid.

Result

a, b) Verify that the system reacts as specified in 4.5.2.

5.3.5.3 Failure of the heading measurement system (4.5.3)

Select scenario 3 and start track control. Wait until the ship is proceeding steadily on a straight leg and perform the following tests.

Restart track control using scenario 3 and repeat the tests during a course change manoeuvre. (~A)

Method

a) Switch off the selected heading sensor.
b) Tag the selected heading input as invalid.

Result

a, b) Verify that the system reacts as specified in 4.5.3.

5.3.5.4 Failure of the speed sensor (4.5.4)

Select scenario 3 and start track control.

Method

a) Switch off the selected speed sensor.
b) Tag the selected speed input as invalid.

Result

a, b) Verify that the system reacts as specified in 4.5.4.

5.3.5.5 Manual changeover from track control to manual steering (4.1.1.13, 4.2.1.2) (~A)

Select scenario 3 and start track control. Wait until the ship is performing a course change manoeuvre for each of the following tests.

Method

a) Switch over to manual steering. Repeat this test with a manoeuvre to the opposite direction.
b) Create a failure condition which renders the track control system inoperative. Then switch over to manual steering. After 3 minutes with manual steering, remove the failure condition of the track control system.

Result

a, b) Verify that

- the system reacts as specified in 4.1.1.13,
- track control cannot be resumed without user intervention, and
- that this can be done by a single operator action.

5.3.5.6 Manual changeover from track control to heading control (4.1.1.14, 4.2.2)

This test is only required for systems which include heading control.

Method

Select scenario 3 and start track control. Wait until the ship is performing a course change manoeuvre and then switch over to heading control. For category A systems perform this test on a straight leg.

Result

Verify that

- the system reacts as specified in 4.1.1.14,
- track control shall not be resumed without user intervention, and
- this can be done by a single operator action.

5.3.6 Display of information

These tests may be combined with and verified during execution of the normal mode and failure mode tests.

5.3.6.1 Continuously displayed information (4.1.1.15, 4.2.2.1, 4.2.2.3)

Method

Locate the display of the information listed in 4.2.2.1.

Result

- Verify that the appropriate steering mode is displayed on any workstation of the EUT where the steering mode can be affected.
- Verify that an appropriate indication is displayed during assisted turns (category B).
- Verify that all information is displayed clearly and continuously on the main conning position.
- Verify that items .4, .5, .7 and .8 are displayed numerically.
- Evaluate the layout of the information displayed.
- Verify that logically related values, such as preset and actual or all TO-/NEXT- data, are displayed as a pair of data or in logically related groups. [9]

5.3.6.2 Information to be provided on demand (4.2.2.2)

The information may be displayed on associated equipment.

Method

Locate the display of the information listed in 4.2.2.2.

Result

Verify that that this information is available on demand.

5.3.7 Operational controls (4.2.1.1, 4.2.1.2)

The previous tests have verified that the requirements in 4.2.1.1 have been met.

[9] This is a subjective judgement and should only be used to point out severely illogical data arrangement, not be used to evaluate differences in implementation.

Method

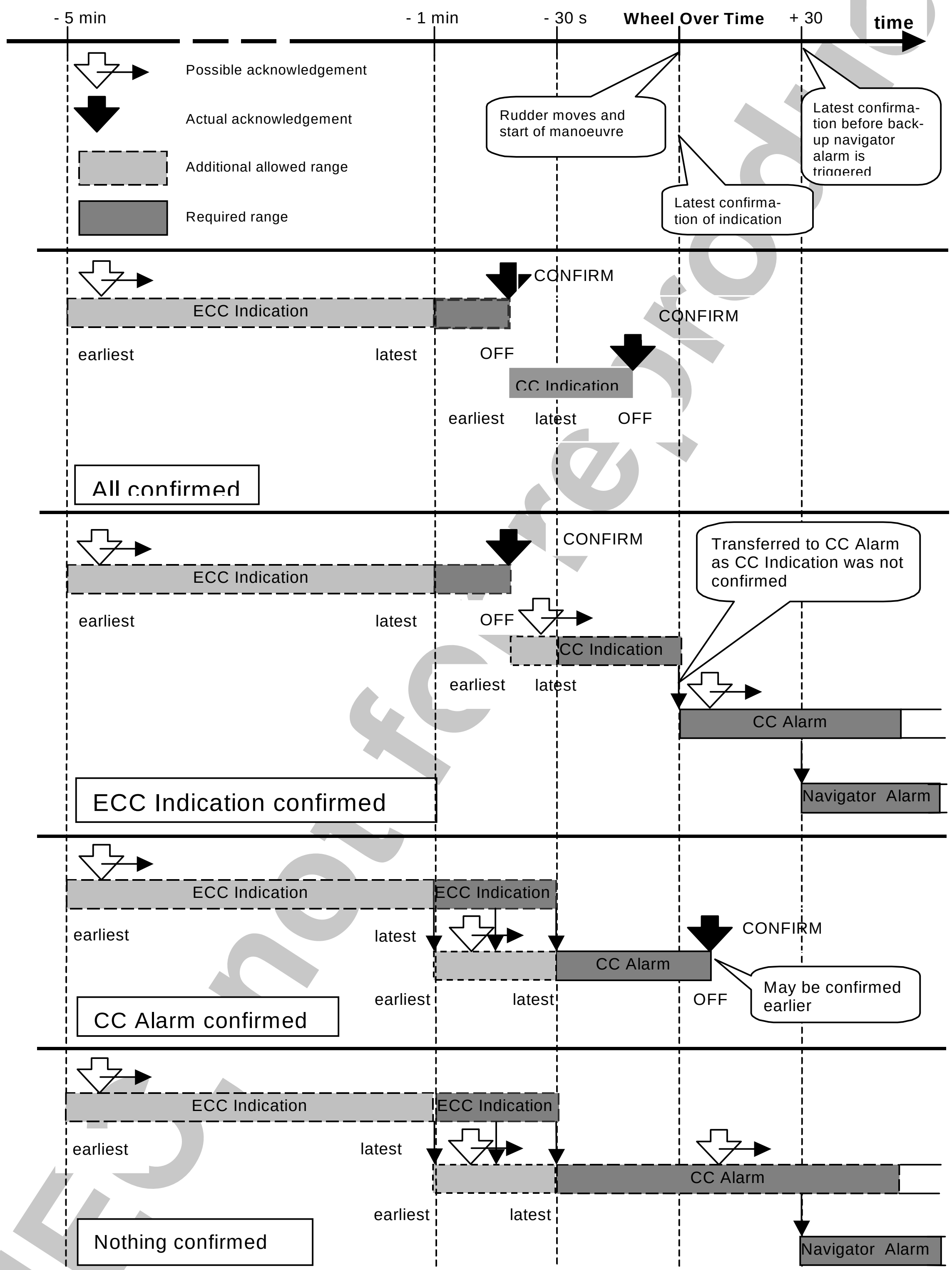
Check installation manual for intended locations of change over controls.

Result

Verify that the location complies with 4.2.1.2. (see also 5.3.5.5, 5.3.5.6)

Annex A
(Normative)

Sequence of course change indications and alarms (~A)



Note: The CC Alarm is triggered 30s earlier when the ECC Indication was not confirmed

Annex B
(Informative)

Speed control

B.1 General

A track control system may be augmented with speed control. Speed control uses the speed/time profile from a route plan to determine the commanded speed of the ship dynamically during the execution of the route. If an interface to the propulsion system is available, this commanded speed should be effected automatically.

Speed control may be applied without route information where the operator manually specifies the commanded speed.

If no propulsion system interface is available, speed control should be used in an advisory manner. It should determine and display actual speed-of-advance and speed-of-advance required to meet the route's speed/time profile.

Track control systems including speed control shall be compliant with the relevant international standards. 10

B.2 Planning

Speed control for a route requires that a speed/time profile be specified for the route. This may be in a variety of forms but generally is given by specifying leg speeds and/or waypoint arrival/departure times. If one or more arrival/departure time is specified along with leg speeds, the route has an absolute time reference. This is most often given as a departure time from the initial waypoint or an arrival time at the final waypoint.

For each leg, a minimum and maximum speed should be specified which would limit the acceptable speeds for that leg. Reasonable defaults for these are: the minimum speed allowed by track control and the full-ahead speed, respectively. The planning system should ensure that the specified speed/time profile be consistent and not violate the ship's allowed speed range.

B.3 Execution – commanded speed generation

B.3.1 Required speed-of-advance

From the track control position source, the system may compute a speed-of-advance along the track. If the route has an absolute time reference, speed control should automatically determine adjustments to the planned speed required to satisfy the time profile. These adjustments would be constrained by the acceptable speed range for each leg. The resulting value is the required speed-of-advance. This should be used in an advisory mode or as an input to the propulsion control system.

B.3.2 Leg speed

From the route speed profile leg speed should be used directly as the commanded speed.

B.3.3 Operator-specified speed

The operator might wish to control speed apart from any route information. In this case, a manually-entered commanded speed would be specified.

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10 IEC 60092-504

B.4 Execution - propulsion control

B.4.1 Open-loop propulsion control

Using the commanded speed, an open-loop control would use an internal conversion function to determine corresponding propulsion control order. No feedback of measured speed would be made to adjust the order.

B.4.2 Closed-loop propulsion control

Using the commanded speed, a closed-loop control would use measured speed to adjust the propulsion control order until the commanded speed is attained.

B.5 Execution – speed monitor

During execution where propulsion control is used, the actual speed should be monitored against the commanded speed.

B.6 Displays

Speed control should display commanded speed, actual speed, source of actual speed, and, when a route is present, speed of advance.

B.7 Failure and alarms

B.7.1 Loss of speed sensor

A valid speed sensor is crucial to closed-loop propulsion control. An alarm should be given upon loss of the speed sensor and the system should fall back to open-loop propulsion control.

B.7.2 Speed not controlled

If the speed monitor indicates that the actual speed deviates significantly from the commanded speed, an alarm should be given and closed-loop control should fall back to open-loop control.

B.7.3 Time profile infeasible

If the speed required to satisfy the route time profile exceeds the leg speed constraints, an alarm should be given.

B.8 Changeover controls and termination of automatic speed control

Changing from automatic to manual speed control should be possible under any condition, including failure in the automatic control system. The changeover controls should be located at or in the vicinity of the main steering position.

Annex C
(Informative)

Track control systems with dual heading controllers

This annex includes specific advice for track control systems which include a primary heading controller and a backup heading controller, both capable of being used for track control.

C.1 Change over from active to back-up heading controller:

- A change over from track control using the active heading controller to track control using the back-up heading controller shall be possible at any time, including a failure of the active heading controller.
- The track control system shall ensure that or be installed such that, the back-up heading controller affects a smooth take over. The back up heading controller shall not use any accumulated rudder bias or other parameter established prior to activation.

C.2 Failure of track control:

If the track controller fails, then a 'track control stopped alarm' shall be given.

- If the active heading controller is still available, the system shall automatically switch over to heading control using the active heading controller as in the corresponding paragraph of 4.5.1.
- If the active heading controller is not available, the system shall allow a manual or automatic switch over to heading control using the backup heading controller, when available, proceeding as in 4.5.1.

However, if the active heading controller fails in a system with a separate track controller and the backup heading controller is still available, an alarm advising operator to switch to the backup heading controller or manual mode shall be given. If the operator switches to the backup heading controller within 1 minute, track control may continue. If the operator does not switch to the backup heading controller before the timeout, a 'track control stopped alarm' shall be given. Automatic switch over to the backup heading controller may be provided with an appropriate indication to the operator.

Annex D
(Informative)

Management of static and dynamic data

According to the functional model of track control (5.1.1.3 and Annex F), the management of static and dynamic data comprises the handling of

- geographic (chart) data,
- ship´s data and reference parameters,
- planning data,
- control data,
- sensor data.

Track control requires a ”consistent common reference system” for all these types of data and information. The following guidelines are based on this condition.

D.1 Management of geographic (chart) data

Geographic data which are processed by different functions within the system should be identical in amount, content and date of issue for the same area or if not, these should be marked as different, in one or more of these categories.

The geodetic datum of the geographic data used for voyage planning/track control, the geodetic datum of the position sensor used and the geodetic datum of other position based functions should be identical or, if not, suitable functions to transform different position data into one common geodetic datum should be provided.

D.2 Management of ships data and reference parameters

The different locations of antennas and other sensor receiving units should be transformed to a common reference location on the ship. This location should be predefined by the manufacturer or adaptable to the special conditions of each ship. In order to align different location information to a common reference location information the consistent common reference system should be established.

All functions should use the identical values for reference parameter of the same type.

D.3 Management of track related data (planning and control)

Dependent on the capabilities of the used planning tool, different options of handling of pre-planned and actual track limits are possible:

a) All track related data defined by means of the planning tool, are equal for all waypoints and legs and are unchangeable/changeable during track control.
b) Track related data defined individually for different waypoints or legs by means of the planning tools and are individually changeable/unchangeable during track control.
c) All track related data defined by means of the planning tool are overruled by the track related data defined by track control functions or may be changed during track control.
d) The pre-planned track does not carry any additional track related data, but these are defined by track control functions or may be changed during track control.

The track control system should be designed in a way, that the user gets full information about the sources of the track related data in use for track control in every situation. Dependent on the solution used, any change of track related data should be harmonised for all system components affected and displayed accordingly. If local track related data of one or more of the system components are overruled by track related data settings by other components this should be brought to the attention of the user by appropriate means.

D.4 Management of sensor data

Any kind of sensor data can be described by the following items:

- method of measurement and/or source of data (sensor or derived from different sources in a filter process),
- measured value,
- time of measurement,
- reference systems,
- validity of measured value,
- pre-processing of the measured value (e.g. smoothed values),
- error characteristics.

A data message should in general carry all of the items stated above except in configurations which use identical data for one particular item in each part of the system (note that this is not fully supported by the applying interface standard IEC 1162 series). The processing of sensor data should take all of this items into consideration as far as needed for the particular task.

Annex E
(Informative)

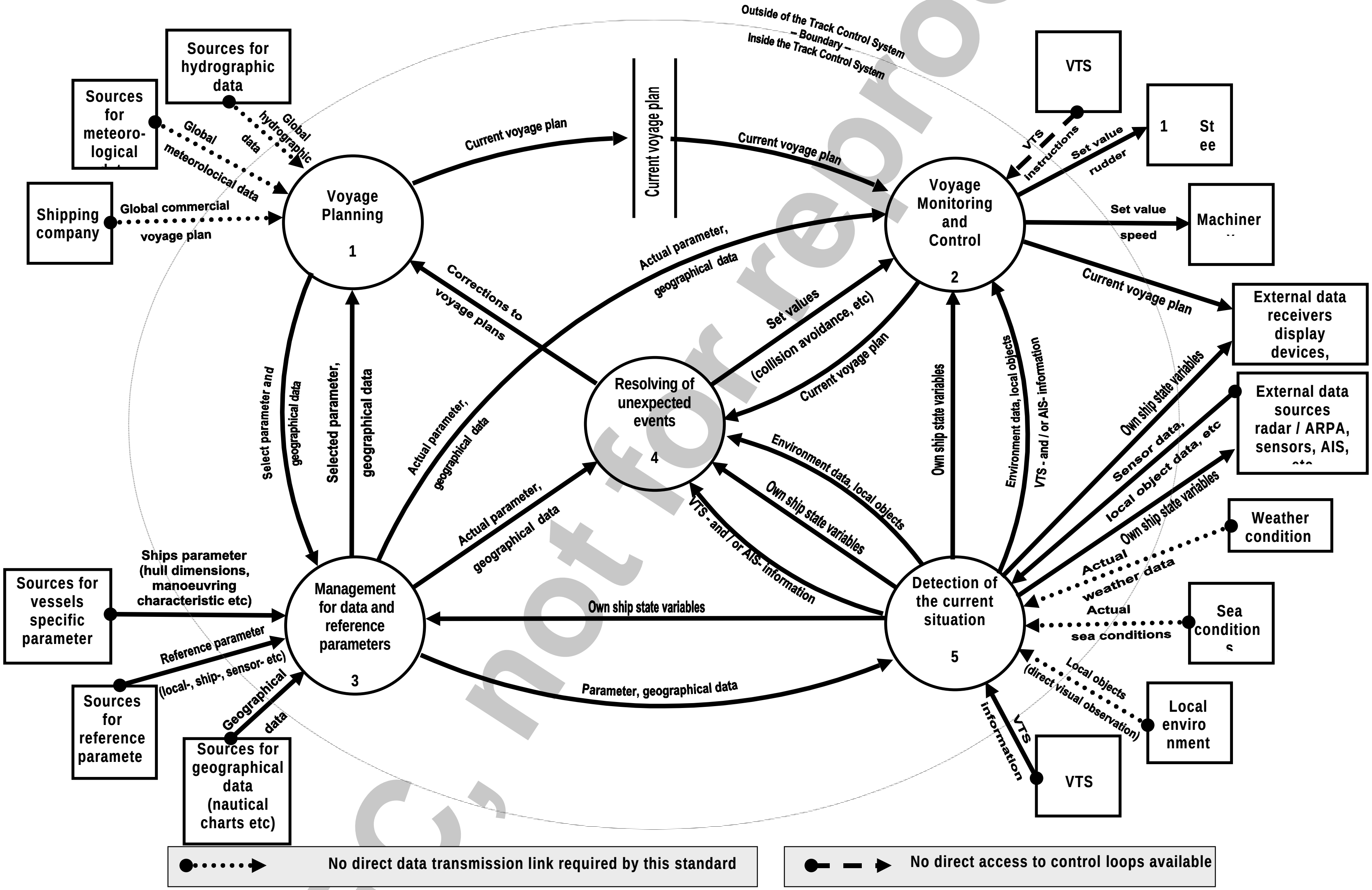
Limits

Section	Item	Required	Recommended
4	Maximum manoeuvring speed	≤ 30 kt	
4	Maximum rate of turn	≤ 10°/sec	
4.1.1.2	Ship's position relative to selected track for starting		≤ 1NM
4.1.1.2	Course difference limit for starting		≤ 60°
4.1.3.2	Maximum position monitoring difference		≤ 1 NM
4.1.3.3	Maximum heading monitoring difference		≤ 25°
4.1.3.6	Maximum cross track limit (for alarm)		≤ 5 NM
4.1.3.7	Maximum course difference limit (for alarm)		≤ 60°

Additional parameters and limits are to be set by the manufacturer or the user taking safety related values into consideration. Those values which are the responsibility of the user shall have appropriate defaults where possible. Otherwise they shall be enforced by the system and/or clearly documented.

Annex F
(Informative)

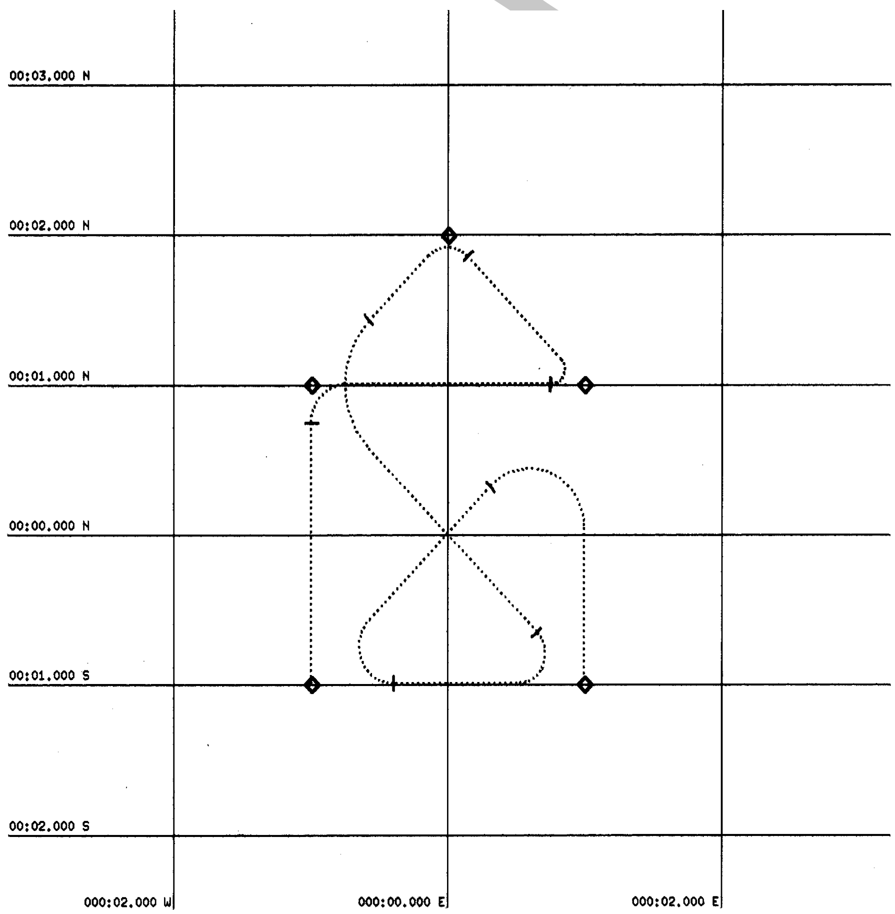
Data flow diagram



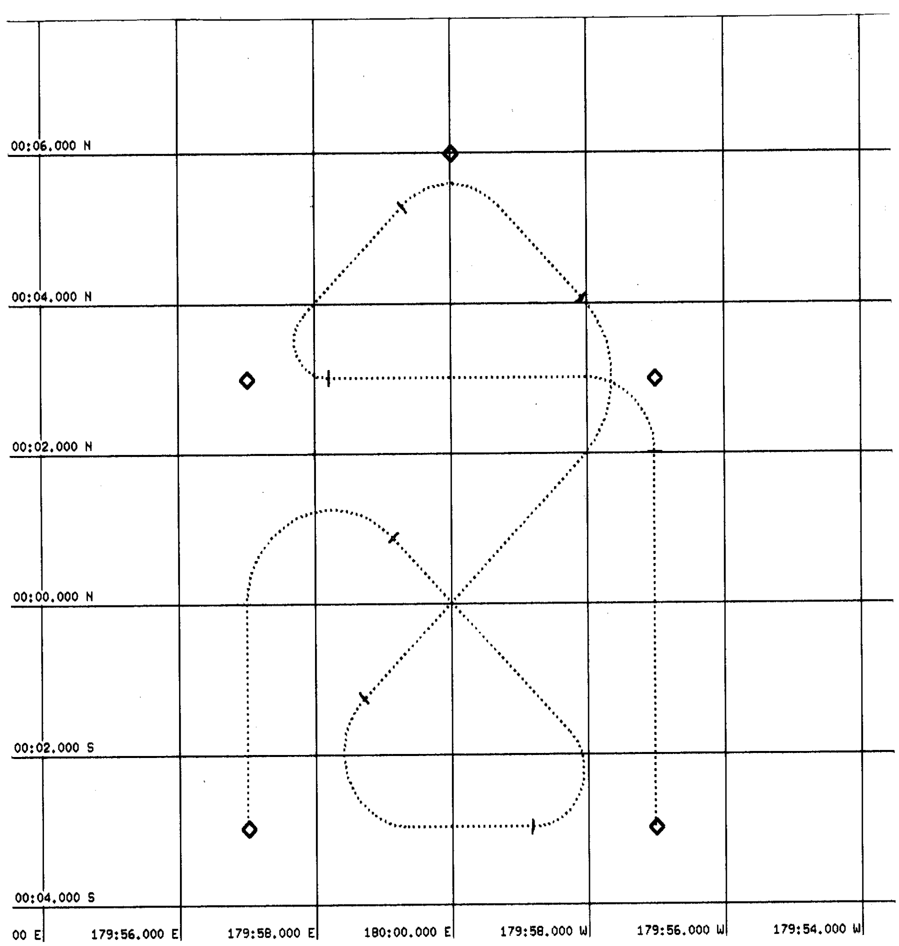
Annex G
(Normative)

Scenario definitions and plots

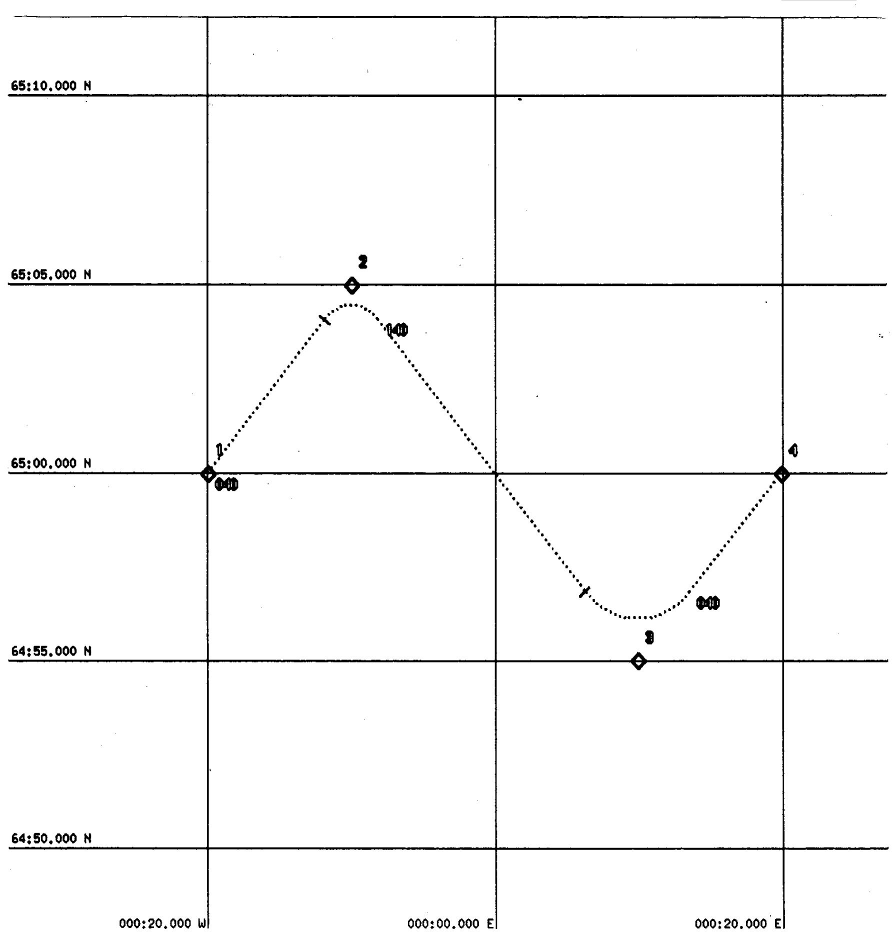
Scenario 1: Complex Track at 0 / 0 with Ship class A (50 m / 20 kt)						
Waypoint No.	**Latitude**	**Longitude**	**Track [deg]**	**Distance [NM]**	**Radius [NM]**	**Estimated R.o.T. [deg/min]**
001	00:01.000 S	000:01.000 W	000.0	2.00	0.25	80
002	00:01.000 N	000:01.000 W	090.0	2.00	0.25	80
003	00:01.000 N	000:01.000 E	315.0	1.41	0.10	200
004	00:02.000 N	000:00.000 E	225.0	1.41	0.20	100
005	00:01.000 N	000:01.000 W	135.0	2.83	0.60	33
006	00:01.000 S	000:01.000 E	270.0	2.00	0.20	100
007	00:01.000 S	000:01.000 W	045.0	2.83	0.25	80
008	00:01.000 N	000:01.000 E	180.0	2.00	0.40	50
009	00:01.000 S	000:01.000 E				



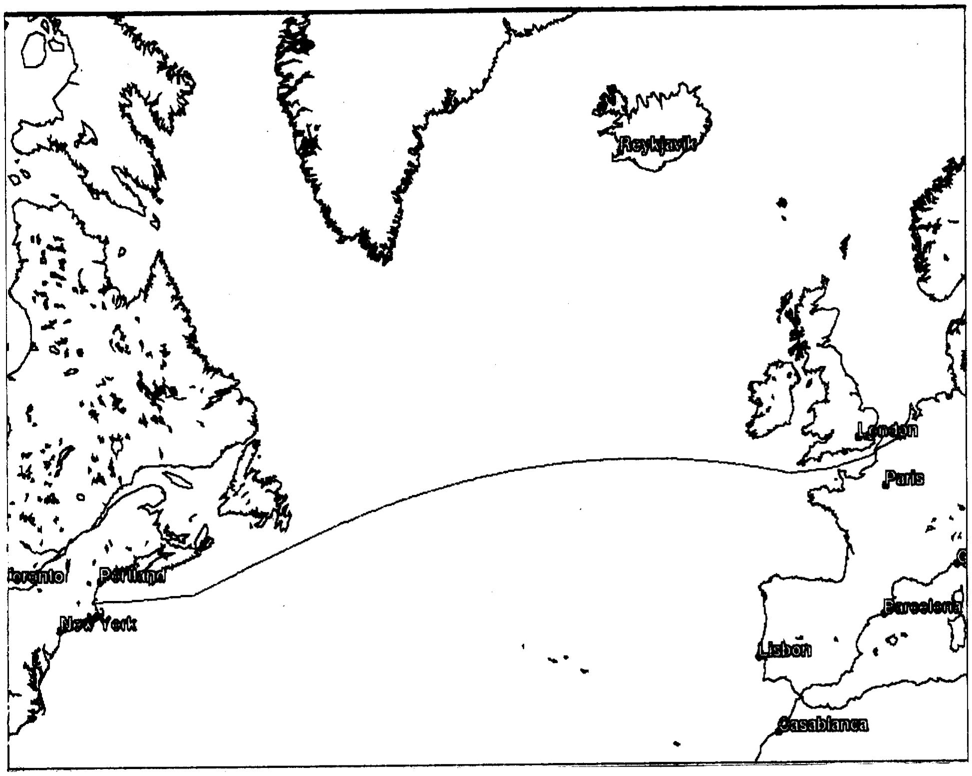
Scenario 2: Complex Track at 0 / 180 with Ship class C (300 m / 10 kt)						
Waypoint No.	**Latitude**	**Longitude**	**Track [deg]**	**Distance [NM]**	**Radius [NM]**	**Estimated R.o.T. [deg/min]**
001	00:03.000 S	179:57.000 W	000.0	6.00	1.00	10
002	00:03.000 N	179:57.000 W	270.0	6.00	1.00	10
003	00:03.000 N	179:57.000 E	045.0	4.24	0.50	20
004	00:06.000 N	180:00.000 W	135.0	4.24	1.00	10
005	00:03.000 N	179:57.000 W	225.0	8.49	1.50	7
006	00:03.000 S	179:57.000 E	090.0	6.00	1.00	10
007	00:03.000 S	179:57.000 W	315.0	8.49	0.75	13
008	00:03.000 N	179:57.000 E	180.0	6.00	1.25	8
009	00:03.000 S	179:57.000 E				



Scenario 3: Zig-Zag Track at 65 / 0 with Ship class B (200 m / 20 kt)						
Waypoint No.	**Latitude**	**Longitude**	**Track [deg]**	**Distance [NM]**	**Radius [NM]**	**R.o.T. [deg/min]**
001	65:00.000 N	000:20.000 W	040.2	6.54	0.50	40
002	65:05.000 N	000:10.000 W	139.8	13.09	1.0	20
003	64:55.000 N	000:10.000 E	040.2	6.55	2.0	10
004	54:00.000 N	000:20.000 E				



Scenario 4: Rhumb Line / Great Circle Atlantic Track (Boston to Rotterdam) with Ship class B (200 m / 20 kt)						
Waypoint No.	**Latitude**	**Longitude**	**Track [deg]**	**Distance [NM]**	**Radius [NM]**	**R.o.T. [deg/min]**
001	42:20.639 N	071:00.786 W	132.1	0.82	0.5	40
002	42:20.090 N	070:59.964 W	112.1	0.40	0.5	40
003	42:19.940 N	070:59.465 W	087.0	1.44	0.5	40
004	42:20.015 N	070:57.525 W	063.6	0.93	0.5	40
005	42:20.429 N	070:56.397 W	026.6	1.77	0.5	40
006	42:22.011 N	070:55.325 W	065.9	0.90	0.5	40
007	42:22.380 N	070:54.210 W	079.5	4.92	0.5	40
008	42:23.275 N	070:47.663 W	065.1	9.53	1.0	20
009	42:27.287 N	070:35.953 W	088.2	126.4	1.0	20
010	42:31.223 N	067:44.616 W	085.4	272.9	.0	20
011	42:53.045 N	061:34.463 W	065.2	202.7	1.0	20
012	44:17:923 N	057:20.346 W	067.1	307.8	1.0	20
013 Great Circle Approximation	46:17.898 N 48:47 N 50:05 N 50:29 N 50:01 N	050:37.294 W 40:00 W 30:00 W 20:00 W 10:00 W	067.1 075.0 082.5 090.0 098.0	1761.2	1.0	20
014	49:38.074 N	006:25.031 W	084.5	147.4	1.0	20
015	49:52.252 N	002:37.903 W	074.5	144.2	1.0	20
016	50:30.788 N	000:59.106 E	049.7	18.33	1.0	20
017	50:42.637 N	001:21.152 E	016.3	13.03	1.0	20
018	50:55.140 N	001:26.929 E	038.1	19.59	1.0	20
019	51:10.551 N	001:46.164 E	041.5	15.62	1.0	20
020	51:22.252 N	002:02.706 E	041.6	46.69	1.0	20
021	51:57.145 N	002:52.725 E	084.9	13.15	1.0	20
022	51:58.304 N	003:13.980 E	082.4	24.71	1.0	20
023	52:01.567 N	003:53.769 E	112.1	7.20	1.0	20
024	51:58.858 N	004:04.605 E				


Reykjavik
London
Paris
Portland
New York
Barcelona
Lisbon
Casablanca

Annex H
(Informative)

Sensor errors and noise models

H.1 Simulation of position sensors errors

For the purpose of this standard, the simulator should generate „noise free true position data" as well as "disturbed position data". The latitude and longitude shall be disturbed independently. The disturbances should be within the permitted tolerance as specified by the appropriate standards for position fixing devices, e.g.:

GNSS IEC 61108 ± 100 m (95% confidence level)

DGNSS IEC 61108 ± 10 m (95% confidence level)

H.1.1 Noise model for simulated position data

The noise superimposed on position data should be calculated in accordance with the model below or any equivalent.

GPS Error model

Define Rand = random[0,1] (top-hat distribution)

For each component of position the error is the sum of N sinusoids, N = 4;
The amplitudes are equal (20 metres for GPS)
F0 = 0.004 Hz

At each step

- Check whether to jump
- If jumping
  calculate time for next jump: period between jumps = -760 * $\log_e$(Rand)

New Frequency = F0* Rand (independently for each sinusoid)
Phase step = 0.4π* Rand (independently for each sinusoid)

- At each step

For each sinusoid: Phase step = deltaTime* Frequency

Position error = Amplitude * sum of {cos(Phase)} over all sinusoids

The standard deviation should be between

- 20 and 30 metres for GPS
- 2 and 3 metres for DGPS

The position error spectrum should conform to the following distribution:

Let x(t) be the values of position error as a function of time.

Let y(f) be the frequency spectrum of x.

Let Y1 be the average of y(f), over the range zero to 0.005 Hz

Let Y2 be the average over the range 0.005 Hz to 0.010 Hz

Let Y3 be the average over the range 0.010 Hz to 0.100 Hz

Then Y1, Y2, Y3 should fall within the following bounds:

Table 1 - Histogram limits. Units are Hz $^{-1}$

	From freq (Hz)	To freq (Hz)	Min	Max
Y1	0	0.005	100	200
Y2	0.005	0.010	10	50
Y3	0.010	0.100	0	10

This is illustrated below:

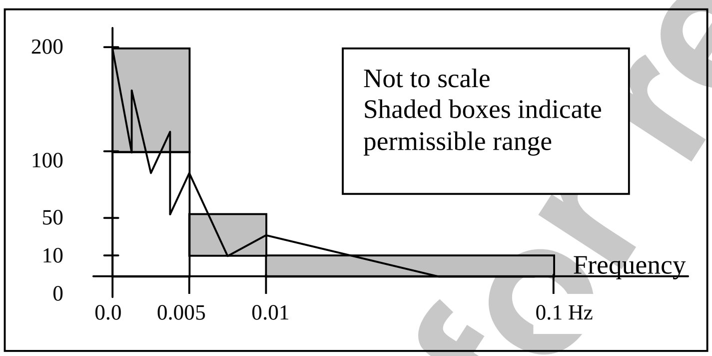


Figure 1. Spectral distribution of modelled GPS errors

H.2 Simulation of heading and speed information

The simulated heading and speed information should be noise free, since constant sensor errors (except heading and speed sensor failure) and dynamic sensor errors have no considerable effect on the test results.

H.3 Simulation of sea state

H.3.1 General

This paragraph describes a mathematical sea state model. The model has been constructed for use with the ship model simulation described in detail in Annex I. The purpose of this sea state model is to generate disturbances which may be applied to the ship model, to simulate the effects of waves. Other models may be used but should give results equivalent to those described below.

A real sea state is generally complicated since the spectrum, directionality, and wave profiles (shapes) vary with conditions of depth, fetch (the uninterrupted distance travelled by waves), wind, current and so on. It is not the intention to reproduce all of these factors here but to generate a representative model which fulfils the following requirements:

- Simplicity
- Applicability to the ship model in Annex I
- Some relationship to recognisable sea states

With regard to the second criterion, the ship model needs a time-sequence of numbers which represent the instantaneous "turning action" of the waves, expressed as an equivalent rudder angle at a standard L/V condition. If at a given time the wave disturbance is +0.01, this is defined to be equivalent to rudder hard over top starboard when the ship forward speed (in metres per second) is 0.01 times its length overall (in metres).

As for the third criterion, Sea States 2 and 5 must be supplied for the tests, in terms of relevant parameters in the model.

The following model is derived, indirectly, from the Bretschneider sea state spectrum, used by the International Towing Tank Committee (ITTC), which describes the dominant frequency and the Significant Wave Height (SWH) and the distribution of energy among a range of frequencies, for a fully developed sea.

H.3.2 Definitions and abbreviations

Within the scope of this paragraph, the following definitions and abbreviations apply:

- Surge Forwards component of ship motion;
- Sway Athwartships component of ship motion (positive to starboard);
- Yaw Rate of turn (positive to starboard);
- SWH Significant Wave Height

H.3.3 Model description

The model generates a square wave disturbance, using a random number generator which produces a flat probability distribution between -1 and +1:

The sea state is generated from a sequence of half-waves. Each half-wave has a duration T_i and a height H_i.

Define $Rand_b$ = random[-1,+1] (top-hat distribution).

Duration:
$T_i = 0.5 * T_0(SS) * (1 + T_r * Rand_b)$ where $T_r = 0.5$;

$T_0(SS)$ is a time constant characteristic of the sea state SS, listed in the table below.

The overall factor of 0.5 reflects the fact that this time applies to just half of the full wave period.

Height:
$H_i = H_0(SS) * (1 + H_r * Rand_b)$ * alternating signs, i.e.±1 where $H_r = 0.5$;

$H_0(SS)$ is the SWH characteristic of the sea state SS, listed in the table below.

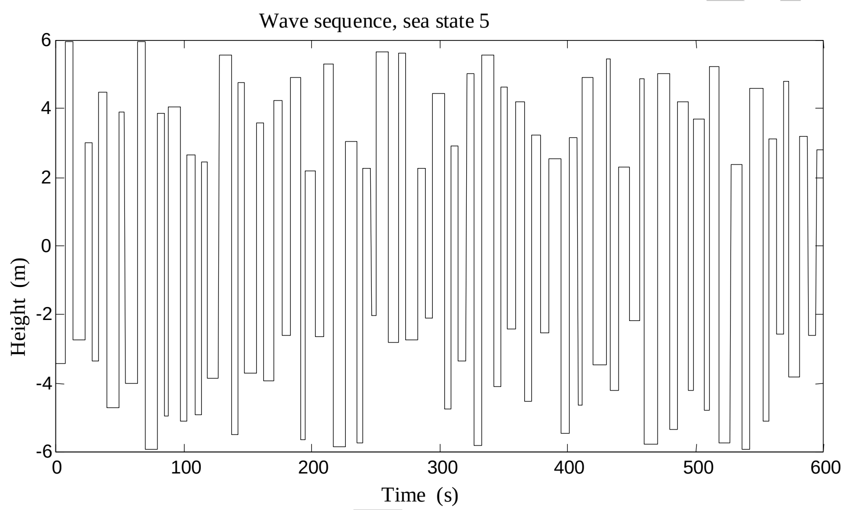
The table below gives values for the characteristic time constant and SWH for Sea States 2 and 5. These are related to the Bretscheider spectrum as follows:

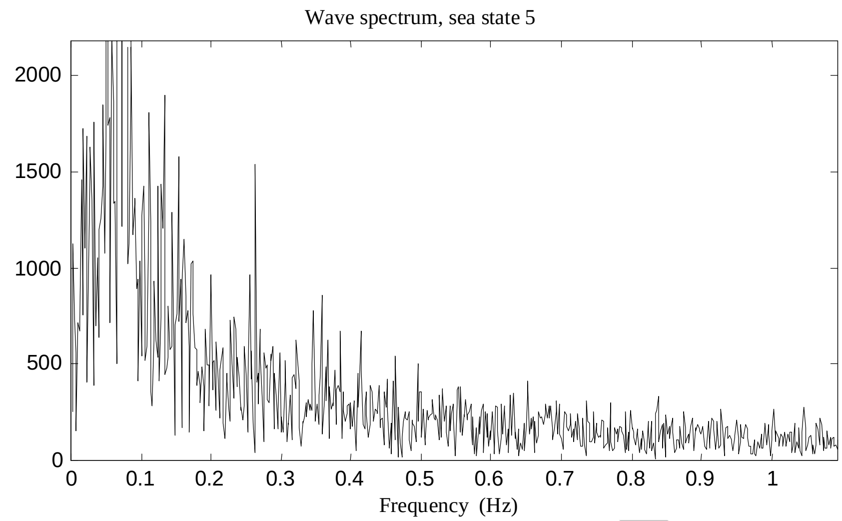
- the time constant is half the typical wave period, since this sequence is expressed in terms of half-waves;
- the height is equal to that which is suggested by the Bretschneider Spectrum.

Heights and periods for half-waves

Sea State (SS)	Period T_0(SS) [s]	Height H_0(SS) [m]
2	5.0	0.5
5	14.0	4.0

The resulting sequence, and the characteristic spectrum are illustrated in the figures below for Sea State 5. It may be seen that the spectrum peaks at about 0.07 Hz, which corresponds to a full wave period of 14 seconds.

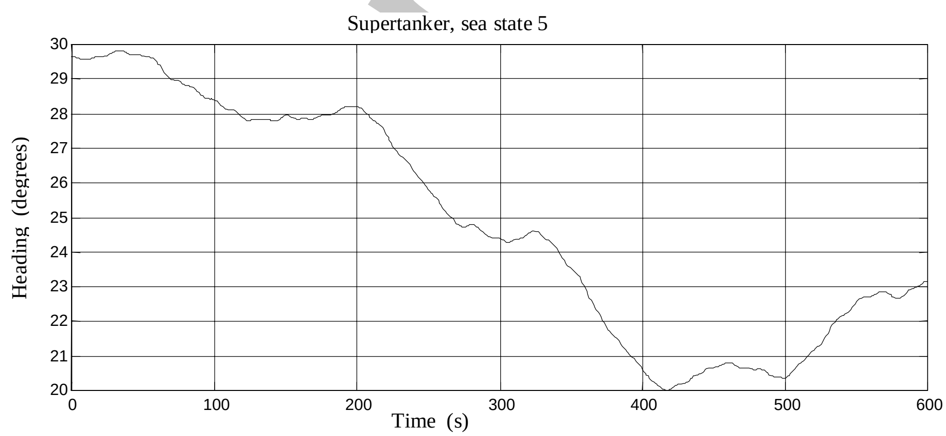


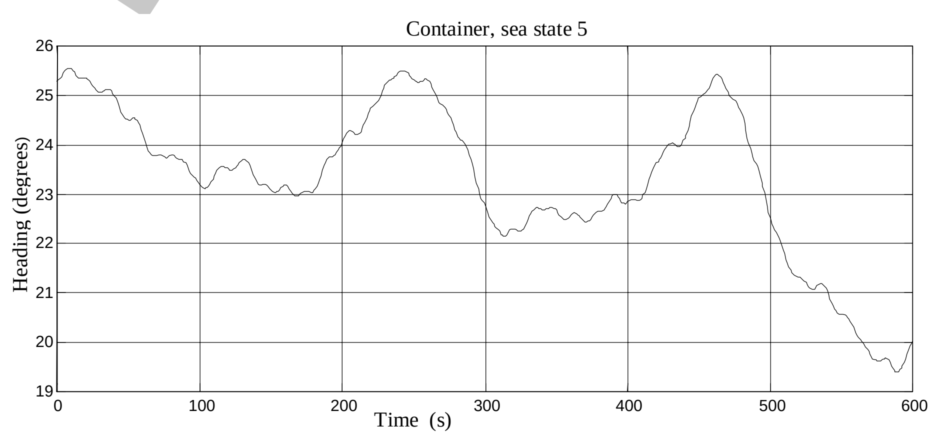


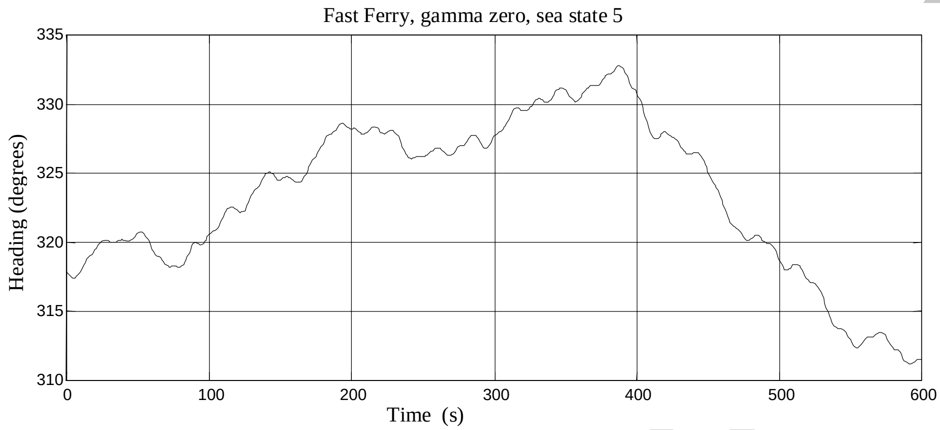
H.3.4 Model implementation

The Sea State model may be incorporated directly into the ship model by means of a scaling factor which relates the "turning action" to the wave height. A scaling factor of 20.0 gives results as illustrated below for the Supertanker, Container and Fast Ferry models.

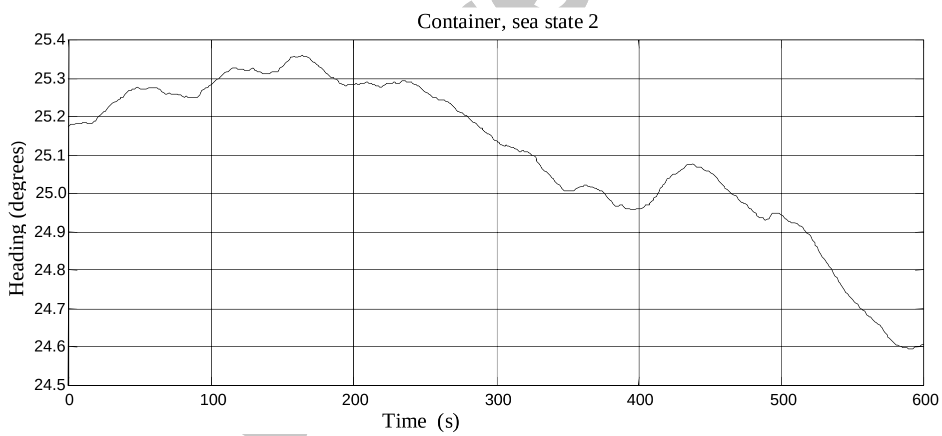
In the case of the Fast Ferry model, the instability coefficient, γ, was set to zero for the test (equivalent to drifting at very low speed) so as to avoid entering a self-sustaining turn.







Graphs for sea state 2 will give similar results albeit on a greatly reduced scale since both the amplitude and the characteristic time scale are reduced to levels where, fon these vessels, the induced heading variations are very small (and are impractical to measure independently of other factors). As an example, the following figure illustrates the behaviour of the Container class in sea state 2:



Annex I
(Normative)

Ship model specification

I.1 General

All functional tests of the track control system shall be performed using the described ship motion simulator. The different ship's and their manoeuvrability can be simulated by using parameter sets as listed in section 8 of this annex.

I.2 Definitions

Within the scope of this Annex, the following definitions apply:

- Surge Forwards component of ship motion;
- Sway Athwartships component of ship motion (positive to starboard);
- Yaw Rate of turn (positive to starboard);

I.2.1 Abbreviations

NMEA National Marine Electronics Association

NMEA 0183 A standard protocol defining electrical connection and serial data formats for interchange of information between marine electronic systems (see Reference 5).

PC Personal Computer

I.2.2 Symbols

C Cosine of heading;

δ_a Rudder setting (achieved);

δ_d Rudder setting (demanded);

δ_a' Normalised rudder setting (achieved);

δ_d' Normalised rudder setting (demanded);

Δ Rudder offset (normalised);

E Position East;

γ Stability coefficient;

Hdg Heading;

I_z Effective moment of inertia for yawing motion;

K_u Coefficient of thrust;

K_r Coefficient of rudder effectiveness;

K_r' Normalised coefficient of rudder effectiveness;

L Length overall;

M_u Effective mass for forward motion;

M_v Effective mass for athwartships motion;

N Position North;

P_a Thrust lever setting (achieved);

P_d Thrust lever setting (demanded);

$P_{\max}$ Maximum thrust lever setting;

P_a' Normalised thrust lever setting (achieved);

P_d' Normalised lever setting (demanded);
R_δ Rudder (achieved) rate of change;
R_δ' Normalised rudder (achieved) rate of change;
R_p Thrust lever (achieved) rate of change;
R_p' Normalised thrust lever (achieved) rate of change;
R_u Resistance coefficient for forwards motion (surge, u);
R_v Resistance coefficient for athwartships motion (sway, v);
R_r Resistance coefficient for rotational motion (yaw, r);
S Sine of heading;
T_δ Rudder hard-over time (limit to limit);
T_p Thrust lever ramp time;
T_E Tidal current East;
T_N Tidal current North;
r Yaw rate;
τ_u Time constant for forwards motion (surge, u);
τ_v Time constant for for athwartships motion (sway, v);
τ_r Time constant for for rotational motion (yaw, r);
u Surge (forwards) velocity component (with respect to water);
v Sway (athwartships) velocity component (with respect to water);
V_{GE} Velocity component East, relative to Earth;
V_{GN} Velocity component North, relative to Earth;
V_{WE} Velocity component East, relative to water;
V_{WN} Velocity component North, relative to water;
W Wave disturbance;
W' Normalised wave disturbance;
X Thrust;
$X_{\max}$ Maximum thrust;
X' Thrust (normalised);
z The vertical axis (downwards).

I.3 Related Documents

ISO CD 16329/16329.2, "Ships and Marine Technology - Heading control systems for high-speed craft", 27-5-1999

I.4 Introduction – background and requirements

This Annex describes a mathematical model which has been designed to provide a simple means of testing track control equipment. Broadly the requirements of the model are:

a) It should be representative of the essential features of ship motion including
   - the reaction of the propulsor machinery to a command
   - the reaction to a propulsive force
   - straight-line resistance
   - the reaction of the rudder machinery to a command
   - the reaction of the vessel to the achieved rudder position

- the sideslip motion of the vessel during a turn

b) The model should be capable of demonstrating the behaviour of a ship which is unstable in straight-line motion, i.e. where the ship may achieve a self-sustaining turn even with the rudder amidships, so that a rudder action in the opposing the turn direction becomes necessary to eliminate an unwanted turn.

c) The model should be capable of being interfaced to commercial-off-the-shelf vessel controller systems without special modification. This means that the inputs to the model should be obtainable from the standard equipment, and the outputs of the model should be suitable as direct inputs to the standard equipment.

d) The model should be simple, so that test houses worldwide may interpret the equations without ambiguity, and build the mathematical equations into computer simulators with minimum difficulty.

As a result of Item (3) in this list, the rudder model has been defined with two options, Option A and Option B, to allow connection either to a direct follow-up system or a standard actuator output using feedback.

I.5 The model - derivation

The model has been derived from Newton's Laws of motion using linear equations to relate the hydrodynamic forces to the respective motions in the horizontal plane. A top-level block diagram of the model is illustrated in Figure 5-1.

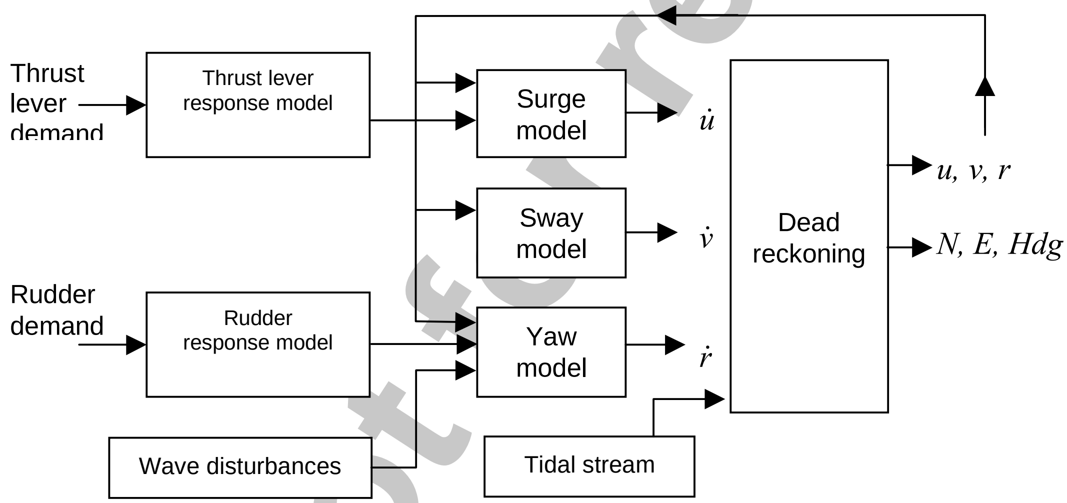


Figure 5-1 High level model block diagram

The individual components of the model are discussed individually in the following sections. In each section, a physically meaningful equation is presented and explained; this is transformed into an alternative form which is more convenient for the purpose of defining readily measurable parameters and for computation.

The model inputs and outputs are summarised in Section I.6, with a full block diagram, where guidance is given as to methods for determining the values of the ship parameters for various classes of vessel and for application under various conditions.

I.5.1 Thrust lever response model

I.5.1.1 Derivation

This model has one input, the demand setting, and two outputs which are the last achieved lever position setting and the thrust. The last achieved setting is fed back internally in the lag calculation. The rate of change is constant, so that the achieved lever position will ramp linearly towards the setpoint and then remain constant.

The thrust is related to the achieved lever position by a linear equation:

$$\dot{P}_a = \begin{cases} +R_p & P_a < P_d \\ 0 & P_a = P_d \\ -R_p & P_a > P_d \end{cases} \qquad (5.1.1)$$

This is subject to minimum and maximum limits imposed on P_a.

$$X = const \times P_a \qquad (5.1.2)$$

where

P_a is the achieved lever setting, and the dot denotes the time-derivative;

P_d is the demanded lever setting;

R_p is the lever response rate;

X is the thrust.

I.5.1.2 Transformed equation

The lever settings and rate are normalised with respect to the maximum value P_{max}:

$$P' = P / P_{\max}, \ \ and \ \ R_p' = R_p / P_{\max}$$

The normalised rate R_p' may be expressed in terms of the time taken for the lever achieved setting to ramp from one extreme to the other, T_p:

$$T_p = 2 / R_p'$$

The thrust is also normalised with respect to its maximal value:

$$X' = X / X_{\max}$$

The equations used in computation are then

$$\boxed{\dot{P}_a' = \begin{cases} +2/T_p & P_a' < P_d' \\ 0 & P_a' = P_d' \\ -2/T_p & P_a' > P_d' \end{cases}} \qquad (5.1.3)$$

where P_a' is constrained within the range -100% to +100%; and

$$\boxed{X' = P_a'} \qquad (5.1.4)$$

Constant parameters to be entered by the user:

T_p Lever ramp time (full astern - full ahead), in seconds;

P_a' Also, the initial value of P_a' should be specified or taken as zero by default (see below).

Run-time inputs:

P_d' Lever demand, normalised (-100% to +100%).

Run-time outputs:

P_a' Lever achieved setting, normalised (-100% to +100%);

X' The thrust, normalised with respect its maximal value (-100% to 100%).

I.5.2 Rudder response model

I.5.2.1 Derivation

The fundamental derivation of the rudder response model is identical to the lever response model, in so far as it represents a mechanism which drives at a given rate of change, towards a setpoint. The rudder model is related to the lever model by the following translation in the algebraic notation:

Table 5-1. Relationship between thrust lever and rudder models

Thrust lever		**Rudder**	
P_a, P_d etc	Lever settings	δ_a, δ_d etc	Rudder settings
R_p	Lever rate	$R_{\square}$	Rudder rate
T_p	Lever time	T_δ	Rudder hard-over time
X	Thrust	-	(see Yaw model)

One difference between the rudder and lever response models is that the rudder response model needs to be adaptable to various possible track control systems. To allow for the different systems which may be tested, the rudder model should be capable of accepting alternative methods of input, viz. the demand setpoint (as for the lever model) or a run-time rate input, i.e. a demanded rate-of-change instead of an absolute setpoint. These two methods are presented below as Option A and Option B below, although it should be noted that the underlying model is fundamentally the same, and the model presented here is a single model with two options for input connections.

Another significant difference between the rudder and lever models is that the rudder model includes an offset. This offset, Δ, represents the effect of miscalibration of the follow-up mechanism. In practice this will result in the ship initiating a turn when the rudder setpoint is amidships, and the control system needs to detect and counteract this offset in order to steer a straight course in the desired direction.

Finally, the rudder does not, in itself, produce a force: the turning moment only arises when the achieved rudder position is combined with water flow. This calculation is deferred to the yaw model, so the output of the rudder response model is only an achieved position.

The equations used in computation are

$$\boxed{\dot{\delta}_a' = \begin{cases} +2/T_\delta & \delta_a' < \delta_d' + \Delta \\ 0 & \delta_a' = \delta_d' + \Delta \\ -2/T_\delta & \delta_a' > \delta_d' + \Delta \end{cases}} \quad \text{(Input Option A)} \qquad (5.2.1\ A)$$

or

$\boxed{\dot{\delta}_a' = R_\delta'}$ (Input Option B) (5.2.1 B)

in both cases, the achieved setting is limited by endstops so that δ_a is limited to the range -100% and +100%.

Constant parameters to be entered by the user:

T_δ Rudder ramp time (full port - full starboard), in seconds (option A);

Δ Rudder follow-up offset (-100% to +100%) (option A; irrelevant for Option B);

also, initial value of δ_a' should be specified or may be defined to be zero by default (see below).

Run-time inputs:

δ_d' Rudder demand, normalised (-100% to +100%) (option A);

R_δ' Demanded rate of change of normalised rudder setting (% per second) (option B).

Run-time output:

δ_a' Rudder achieved setting, normalised (-100% to +100%).

I.5.3 Surge response model

I.5.3.1 Derivation

The surge response model calculates the forwards acceleration which is brought about by the thrust X (provided by the propulsor) and the hydrodynamic resistance to forwards motion, which is assumed to vary linearly with forward speed. There is also a term which describes the effect of sideways motion coupled with rotation (yaw); essentially this term takes into account the fact that the ship axes are rotating and do not constitute an inertial frame of reference.

$$M_u \dot{u} = X + M_u v r - R_u u \qquad (5.3.1)$$

where

M_u is the mass associated with forwards acceleration;

u is the forwards component of ship velocity, and the dot denotes the time-derivative;

X is the forward thrust imparted by the propulsor;

v is the lateral component of ship velocity (positive to starboard);

r is the yaw, or rate of turn about the vertical axis (positive to starboard);

R_u is the linear coefficient of hydrodynamic resistance.

I.5.3.2 Transformed equation

The equation is transformed by first dividing by M_u, and then defining parameters

$$\tau_u = M_u / R_u \qquad (5.3.2)$$

τ_u is the time constant of the linear response model;

$$u_{\max} = X_{\max} / R_u \qquad (5.3.3)$$

$$K_u = u_{\max} / \tau_u \qquad (5.3.4)$$

K_u is the coefficient of thrust, relating the maximum forward speed to the time constant. Note that the value of K_u is derived from easily measured or defined quantities.

Then the equation used in computation becomes

$$\boxed{\dot{u} = K_u X' + vr - u / \tau_u} \qquad (5.3.5)$$

Constant parameters to be entered by the user:

u_{max} maximum speed, metres per second;

τ_u acceleration time constant, seconds;

also, the initial value of u should be specified or taken as zero by default.

Run-time inputs:

X' thrust (normalised with respect to its maximum value) (-100% to +100%);

u, v components of velocity, metres per second;

r rate of turn (yaw), radians per second.

Run-time output:

$\dot{u}$ time-derivative of u, metres per second per second.

I.5.4 Sway response model

I.5.4.1 Derivation

The sway response model is directly analogous to the surge response model, albeit with a few notable differences. The sway response model calculates the lateral acceleration, which is brought about by the lateral hydrodynamic forces acting on the hull.

A simplifying assumption is that the lateral force imparted by the rudder is ignored, i.e. the rudder is effectively placed at the centre of gravity. This assumption does not have any significant impact on the resulting motion of the vessel other than a subtle lateral movement of the centre of gravity which may be observed, on a real vessel, as a turn is initiated: the simplified model does not exhibit this effect. While it would be a simple matter to introduce this effect, it would not afford any benefits in terms of the purpose of this model for testing track control systems.

The hydrodynamic resistance to sideways motion is assumed to vary linearly with sideways speed. There is also a term which describes the effect of forward motion coupled with rotation (yaw); as above, essentially this term takes into account the fact that the ship axes are rotating and do not constitute an inertial frame of reference.

$$M_v \dot{v} = -M_v ur - R_v v \qquad (5.4.1)$$

where

M_v is the mass associated with sideways acceleration;

v is the sideways component of ship velocity, and the dot denotes the time-derivative, (positive is to starboard);

u is the forwards component of ship velocity;

r is the yaw, or rate of turn about the vertical axis (positive to starboard);

R_v is the linear coefficient of hydrodynamic resistance to lateral motion.

I.5.4.2 Transformed equation

The equation is transformed by first dividing by M_v, and then defining a parameter

$$\tau_v = M_v / R_v \qquad (5.4.2)$$

τ_v is the time constant of the linear response model

Then the equation used in computation becomes

$$\boxed{\dot{v} = -ur - v/\tau_v} \qquad (5.4.3)$$

Constant parameters to be entered by the user:

τ_v Acceleration time constant, seconds;

also, the initial value of v should be specified or taken as zero by default.

Run-time inputs:

u, v components of velocity, metres per second;

r rate of turn (yaw), radians per second.

Run-time output:

$\dot{v}$ time-derivative of v, metres per second per second.

I.5.5 Yaw response model

I.5.5.1 Derivation

The yaw response model calculates the rate of change of the rate of turn about the vertical axis (yaw) which is brought about by the turning moment. The turning moment is provided by a combination of the rudder achieved position, δ_a, and the water flow over the rudder. The water flow over the rudder is dominated by the effect of the propeller, in the regimes of interest to this model, and is represented by the term $K_u X' \tau_u$ which represents the forward speed which is achieved, in equilibrium straight line motion, for a (normalised) thrust X'.

The turn is opposed by the hydrodynamic resistance to rotational motion, which is assumed to vary linearly with the rate of turn.

There is also a term which describes the effect of sideways motion coupled with the lever arm distance which may exist between the centre of lateral pressure and the centre of gravity. If the lateral resistance force acts aft of the centre of gravity, the slipping motion in the turn will tend to generate an opposing moment, so that the vessel will tend to straighten out, i.e. it is stable in a straight line. If on the other hand the lateral resistance force acts forward of the centre of gravity, the sideslip will tend to aggravate the turn. Clearly this effect will be more pronounced at speed, and there is a point where the vessel will become unstable in straight-line motion. If the centre of lateral pressure coincides with the centre of gravity, the vessel is neutrally stable; there remains some positive stability from the simple resistance to turning motion.

$$I_z \dot{r} = K_r \left(\delta_a \frac{K_u X' \tau_u}{L} + W \right) + \gamma L R_v (v - \gamma L r) - R_r r \qquad (5.5.1)$$

where

I_z is the moment of inertia associated with rotation about the z axis (which points vertically downwards), i.e. yaw;

r is the rate of turn, i.e. yaw rate, and the dot denotes the time-derivative;

K_r is a constant of proportionality;

δ_a is the achieved rudder position;

u is the forwards ship speed;

$K_r \delta_a . K_u X' \tau_u / L$ is the turning moment imparted by the rudder, which is dependent on the rudder achieved position and the speed of water flow;

$K_r\ W$ is the turning moment imparted by wave disturbances;

γ is the stability coefficient, i.e. the distance of the centre of pressure aft of the centre of gravity, normalised to the ship length L;

L is the ship length;

R_v is the linear coefficient of hydrodynamic resistance to lateral motion;

$(v - \gamma L r)$ is the lateral component of ship velocity (positive to starboard), measured at the centre of hydrodynamic pressure;

R_r is the linear coefficient of hydrodynamic resistance to rotation (yaw);

r is the yaw, or rate of turn about the vertical axis (positive to starboard).

I.5.5.2 Transformed equation

The equation is transformed by first dividing by I_z, and then defining parameters

$$\tau_r = I_z / R_r \qquad (5.5.2)$$

τ_r is the time constant of the linear response model

$$K_r' = \frac{r(\delta_a', X')}{\delta_a' \tau_r} \frac{L}{K_u X' \tau_u} \qquad (5.5.3)$$

K_r' is the normalised coefficient of rudder moment, relating the steady-state yaw rate to the propeller thrust and normalised rudder position in the absence of any stability effects, i.e. with $\gamma = 0$. A practical method of estimating K_r' is given in Section 6.1.

Using Equation (5.4.2), the equation is re-written

$$\dot{r} = K_r' \left(\frac{K_u X' \tau_u}{L} \delta_a' + W' \right) + \frac{\gamma L M_v (v - \gamma L r)}{I_z \tau_v} - \frac{r}{\tau_r} \qquad (5.5.4)$$

For this computation, the equation has further been simplified by relating the moment of inertia to the mass and length, using a simple equation which relates a the moment of inertia of a uniformly dense rod to its mass and length, i.e.

$$I_z = M_v L^2 / 12$$

This is without loss of generality as the coefficient γ is a quantity which is set by the user. Using this relationship, the equation becomes

$$\boxed{\dot{r} = K_r'\left(\frac{K_u X'\tau_u}{L}\delta_a' + W'\right) + \frac{12\gamma(v - \gamma L r)}{L\tau_v} - \frac{r}{\tau_r}} \tag{5.5.5}$$

Constant parameters to be entered by the user:

K_r' yaw coefficient, in units of reciprocal seconds;

τ_r time constant, seconds;

stability coefficient, dimensionless;

L ship length overall, metres.

Also, the initial value of r should be specified or taken as zero by default.

Run-time inputs:

δ_a' rudder achieved position (normalised with respect to its maximum value, -100% to +100%);

W' wave disturbance turning moment, normalised such that a wave disturbance of 0.01 is defined to be equivalent to rudder hard over with u/L = 0.01; W' is dimensionless, and lies in the range –100% to +100%.

$K_u X'\tau_u/L$ Thrust, multiplied by the thrust coefficient and divided by the forwards motion time constant and the ship length. This quantity is in units of reciprocal seconds;

v sideways component of velocity, metres per second;

r rate of turn (yaw), radians per second.

Run-time output:

$\dot{r}$ time-derivative of r, radians per second per second.

I.5.6 Integration (Deduced Reckoning)

The process of integrating the accelerations, to yield velocity components, yaw rate, heading and position is well known and is briefly outlined below. For the purpose of testing track control systems, it is necessary to include the effects of a tidal stream.

The first stage in the process is to recalculate the components of speed through the water, u and v, from previous values of the speed over the ground, heading, and the tidal flow. This calculation might be omitted if the tidal stream were to be constant; but if the tidal stream is to be suddenly altered, the calculation should take place at this point. This ensures that the new tidal stream, on first introduction, introduces movement of the water relative to the ship, and this produces hydrodynamic forces on the ship which reacts by accelerating accordingly. (If the calculation were omitted, the ship would immediately be carried by the new tidal current, implying that the tidal set and drift is imposed suddenly and immediately, with a step change in ship velocity relative to Earth, which would be contrary to Newtonian dynamics).

$$\begin{pmatrix} V_{WN} \\ V_{WE} \end{pmatrix} = \begin{pmatrix} V_{GN} \\ V_{GE} \end{pmatrix} - \begin{pmatrix} T_N \\ T_E \end{pmatrix}$$

and then

$$\begin{pmatrix} u \\ v \end{pmatrix} = \begin{pmatrix} C & S \\ -S & C \end{pmatrix} \begin{pmatrix} V_{WN} \\ V_{WE} \end{pmatrix}$$

where C and S and the cosine and sine of the heading and V_{WN} and V_{WE} are the water-velocity components based on the (N,E) coordinate system.

The second stage in the process is to integrate the rates of change to obtain velocity and rate of turn (yaw).

$$u = \int \dot{u} dt$$

$$v = \int \dot{v} dt$$

$$r = \int \dot{r} dt$$

The third stage is to integrate the yaw rate to obtain heading:

$$Hdg = \int r dt$$

The fourth stage is to transform the ship-related velocity components to an absolute coordinate system based on N and E:

$$\begin{pmatrix} V_{WN} \\ V_{WE} \end{pmatrix} = \begin{pmatrix} C & -S \\ S & C \end{pmatrix} \begin{pmatrix} u \\ v \end{pmatrix}$$

where C and S are defined as above.

The tidal stream is added in to yield the ground-velocity components V_{GN} and V_{GE}:

$$\begin{pmatrix} V_{GN} \\ V_{GE} \end{pmatrix} = \begin{pmatrix} V_{WN} \\ V_{WE} \end{pmatrix} + \begin{pmatrix} T_N \\ T_E \end{pmatrix}$$

where T_N and T_E are the tidal stream components.

Finally, V_{GN} and V_{GE} are integrated to obtain the position of the vessel:

$$N = \int V_{GN} dt$$

$$E = \int V_{GE} dt$$

Constant parameters to be entered by the user:

T_N, T_E tidal stream; alternatively entered as speed and direction.

Run-time inputs:

$\dot{u}, \dot{v}, \dot{r}$ component of acceleration and rate of change of yaw.

Run-time outputs:

u,v,r	components of velocity and yaw;
V_{WN},V_{WE}	components of water-velocity, in (N,E) coordinates;
V_{GN},V_{GE}	components of ground-velocity, in (N,E) coordinates;
Hdg	heading;
N,E	ship position.

I.6 Summary and block diagram

I.6.1 Constant inputs

The constant parameters to be entered by the user are listed in Table 6-1.

Table 6-1. Constant parameters of the model

item	comments
T_p	Time for the thrust to ramp from min to max
T_δ	Time for the rudder to swing from stop to stop
Δ	Rudder follow-up offset
u_{max}	Maximum speed
τ_u	Time constant, surge
τ_v	Time constant, sway
K_r'	(Normalised) Yaw coefficient, defined by Equation (5.5.3)
τ_r	Time constant, yaw
γ	Stability coefficient, physically corresponds to the position of the centre of lateral pressure, normalise with respect to length L; 0 is neutral; typical values lie in the range -0.1 (unstable) to +0.1 (stable).
L	Vessel length overall

In addition to these parameters, the model should also be provided with user-input or default values for the initial conditions, i.e. start position and heading; start velocity and yaw rate; start rudder and lever achieved values. In all cases zero may be specified as a valid starting value.

I.6.1.1 Estimating parameters for a given vessel or class

Most of the ship parameters are directly measurable or may even be estimated with reasonable accuracy for a given class of ship. The model is a linearised approximation and is not intended as a comprehensive solution; consequently the parameters may be estimated with considerable latitude and the best choice of parameters may be different for different regimes (speeds) of operation. It should also be borne in mind that changes of some of the parameters may only have a small effect on test results.

The sway time constant τ_v may be obtained by observing the drift characteristics during a turn. In the steady state condition, all time derivatives are zero and equation (5.4.3) yields

$$\tau_v = -\frac{v}{ur} \qquad (6.1)$$

where all the parameters on the right hand side are directly measurable.

Similarly, the surge time constant τ_u may be obtained by observing the drop in forwards speed during a turn. In the steady-state condition, Equation 5.3.5 leads to

$$\tau_u = \frac{\partial u}{\partial (vr)} \qquad (6.2)$$

In practice, this means simply observing the drop in forwards speed during a steady-state turn, compared to straight-ahead motion with the same lever setting.

The yaw time constant, τ_r, is measurable from a graph of the yaw rate as a turn is initiated. It is likely to be of the same order of magnitude as the sway time constant τ_v because it arises from a physically related phenomenon, viz. the resistance to water flow sideways under the hull: if this is uniformly distributed along the length of the vessel, τ_r and τ_v will be similar and for practical purposes, the same value may be used for both.

The yaw coefficient and the stability coefficient are measurable from a set of turning circle data. A first approximation may be made on the assumption that $\gamma = 0$, giving a value for K_r' from Equation 5.5.3. For the purposes of setting up models for simulation testing, this is probably a good approach. A more accurate estimate may be made by performing turning circle trials with different values of u/L and rudder settings. Equation (5.5.5) may be re-arranged, for steady state conditions, to yield values of K_r' and γ from a set of graphs in which r is plotted against $K_r'\delta_a'u/L$.

The stability coefficient is generally likely to be in the region -0.1 to +0.1 and will, in practice, vary with speed. As explained in the derivation (Section I.5.5.1), this figure describes the position of the centre of lateral resistance, in terms of ships lengths. For example, a skeg fitted forward of the centre of gravity will tend to make the vessel unstable. For the purposes of autopilot testing, it might be recommended that the system be tested with neutral stability ($\gamma = 0$) and with some instability using a specified negative value, and a certain minimum speed, in a combination which is found to represent a suitably difficult but not impossible condition.

In setting up a model for tests, it is worth noting that the model will not exhibit a self-sustained turn unless the forward speed exceeds a threshold value. The threshold condition may be derived from Equation (5.5.5) to be

$$\frac{u}{L} > \frac{\gamma}{T_v} + \frac{1}{12\gamma T_r} \qquad (6.3)$$

and, as stated earlier, $\gamma < 0$. With these conditions satisfied, the vessel will enter a turn (if an initial impetus is provided to port or starboard) and the turn will increase and settle on a value such that the forward speed is reduced to the threshold condition implied by Equation (6.3). Thus, given a self-sustained rate of turn and an initial forward speed, γ may be calculated from Equations (6.1) to (6.3).

I.6.2 Run-time inputs

Run-time inputs to the system are listed in Table 6-2.

Table 6-2. Run-time inputs

Item	comments
P_d'	Lever demand (normalised)
δ_d' or R_d'	Rudder (normalised) demand (option A) or rate (option B)
W'	Wave disturbance function (normalised with respect to rudder action)
Tidal stream	Speed and direction, or N and E components

The wave disturbance function may take the form of a prescribed sequence of values and durations, for example as specified in ISO16329.

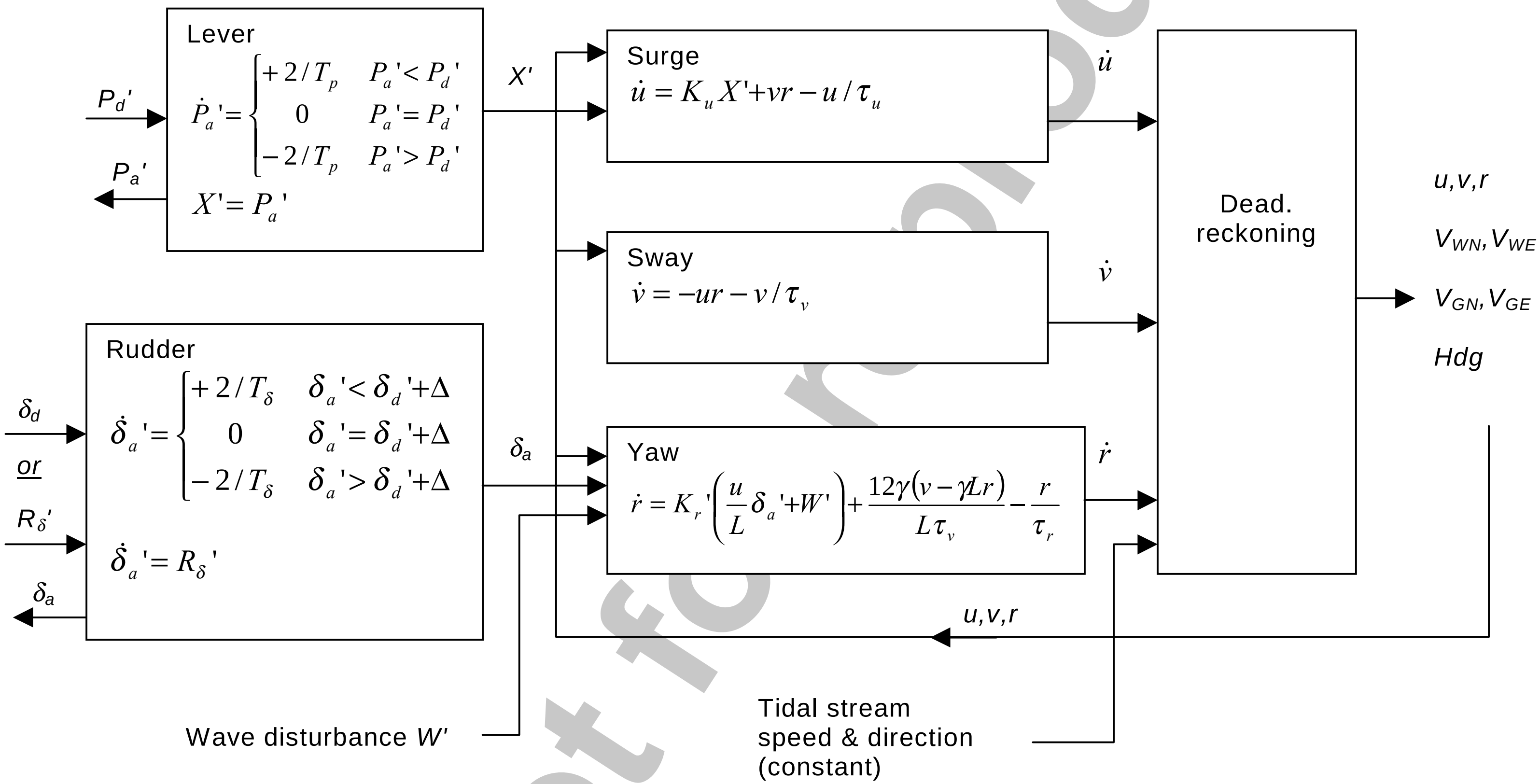
I.6.3 Outputs

Model outputs are listed in Table 6-3.

Table 6-3 Model outputs

Item	comments
P_a'	Lever achieved (normalised)
X'	Thrust (normalised)
δ_a'	Rudder achieved (normalised)
$\dot{u}, \dot{v}, \dot{r}$	Accelerations in ship coordinates, and rate of change of yaw
u, v, r	Velocity in ship coordinates, and yaw
V_{WN}, V_{WE}	Water velocity components with respect to fixed *(N,E)* axes
V_{GN}, V_{GE}	Ground velocity components with respect to fixed *(N,E)* axes
Position	With respect to fixed *(N,E)* axes
Heading	With respect to North

I.6.4 Model block diagram



I.7 Application of the model to system testing

In developing the model, care has been taken to ensure that the inputs and outputs correspond to those which are found on standard track control systems. It is worth noting that the connections provided on track control systems may vary according to manufacturers and types.

As far as lever settings are concerned, these are manual or follow-up (direct demand) rather than rate demands so the optional rate-input is not provided.

The machinery interface is provided with several options for connection, depending on whether the electronic "decision-making" system is being tested, or whether the test includes the mechanical means for driving the lever and rudder. It is arguable that these actuators, which are often provided as part of the system and can have a dramatic impact on performance, should be tested as part of the whole system.

I.7.1 Testing system only, without rudder actuators

I.7.1.1 Systems which output an absolute rudder demand ("follow-up")

For follow-up systems which output absolute value demands, Option A is selected in Section I.5.2. The demanded setting is converted from a voltage to a normalised numerical value, and applied directly to the P_δ run-time input as illustrated in Figure 7-1.

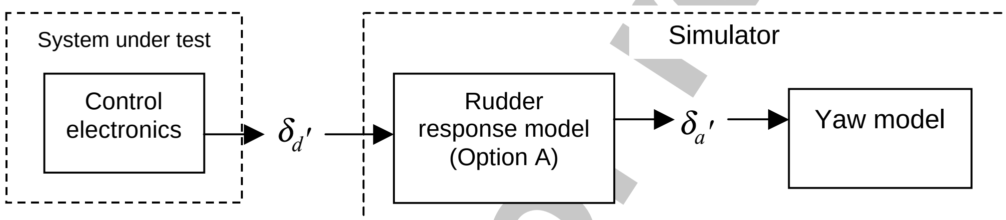


Figure 7-1. Application with simple follow-up

The model is capable of introducing an offset between the demand and the steady-state achieved settings, so as to simulate the effect of asymmetry in the ship behaviour, as may indeed arise from a miscalibration of the rudder follow-up mechanism.

I.7.1.2 Systems which output a rudder actuator command

Many autopilot devices have a feedback connection to the vessel, in which the demand is issued as a required rate of change, and the vessel feeds back a voltage which represents the achieved setting. It is worth noting that such systems do not have a calibrated zero position (e.g. a voltage which is guaranteed to represent rudder-amidships). The control system must be capable of effectively calibrating itself to whatever the rudder-amidships voltage happens to be on a particular vessel, for example by accruing a corresponding offset in an integrator.

In this case the model may be connected to the autopilot system by means of the demanded rate of change R_{δ}' and the achieved value δ_a is connected to the feedback input of the autopilot system. This arrangement, illustrated in Figure 7-2, allows for a bipolar/zero rate input, or for a variable rate input for fine control of small rudder angles.

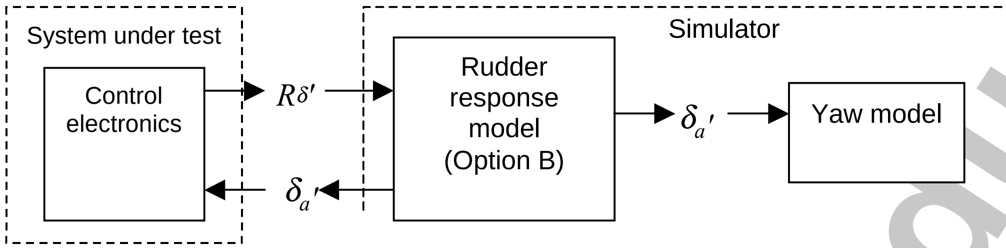


Figure 7-2 Control system using actuator outputs and feedback

I.7.2 Testing the whole system including actuation mechanism

If the actuator mechanism is included within the system under test, it is necessary to use its achieved setting in place of the rudder response model.

One way to achieve this is to bypass the rudder model completely, applying the controller output to the input of the yaw model as illustrated in Figure 7-3.

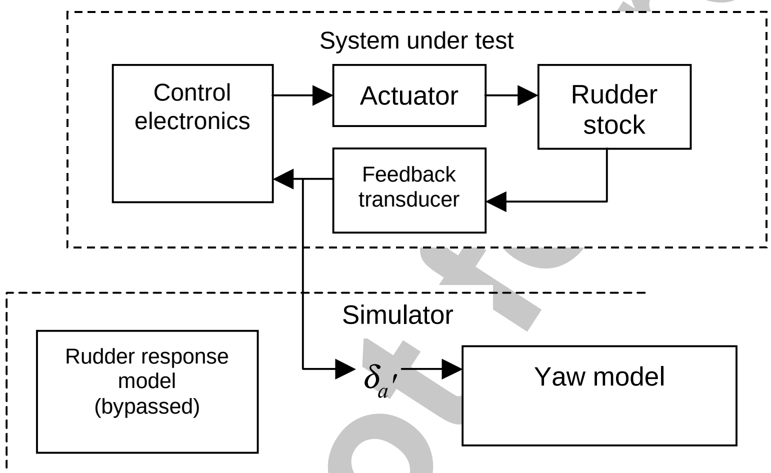


Figure 7-3. System with actuator mechanism, bypassing the rudder reponse model

Alternatively the system may be configured using the follow-up arrangement (Option A) with a ramp rate that is faster than that of the system under test, so that the model effectively keeps the rudder achieved position in step with the actuator output. This is illustrated in Figure 7-4.

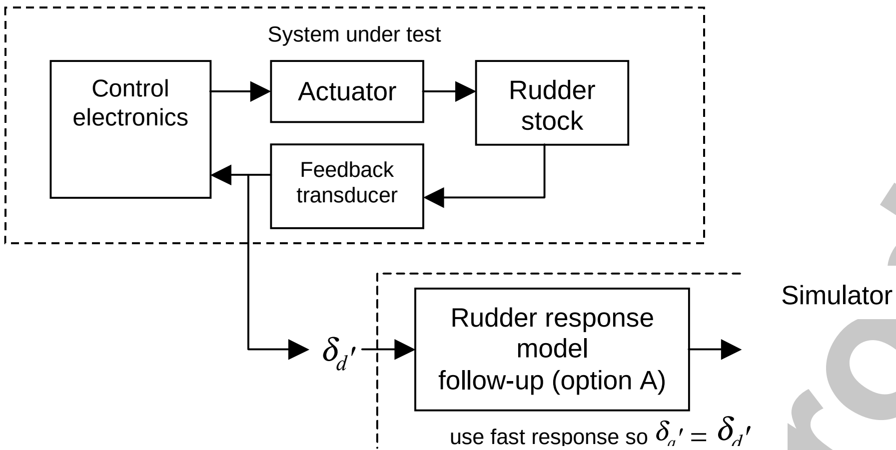


Figure 7-4. System with actuator mechanism, using a fast rudder response time in the model

I.7.3 Model outputs: input to system under test

Other system outputs must be converted to a format that is suitable for input to the system under test. A conveniently widespread format is IEC 61162-1/2, which provides for data transfer using serial data links. All the required data fields are provided by the model as outputs.

I.8 Ship parameter sets

Three sets of ship parameters have been created to represent, broadly, three classes of vessel to be used in the tests. These are presented in Table .

Table 8-1 Parameter sets for three ships

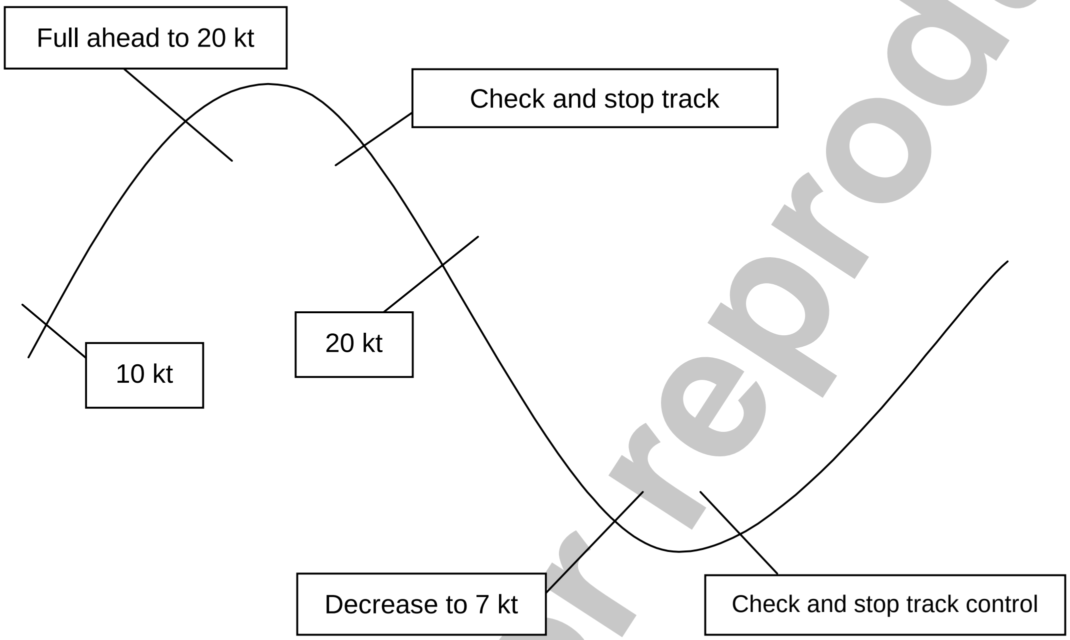
Parameter	Ship 1	Ship 2	Ship 3
Type	**Supertanker**	**Container**	**Fast ferry**
L (m)	395	250	60
T_p (s)	30	30	20
T_R (s)	30	30	12
Δ (%)	0	0	0
u_{max} (kt)	8	25	70
Kr' (s^{-1})	0.008	0.015	0.050
τ_u (s)	800	600	150
τ_v (s)	50	15	15
τ_r (s)	40	15	15
γ	0	0	-0.050

Annex J
(Informative)

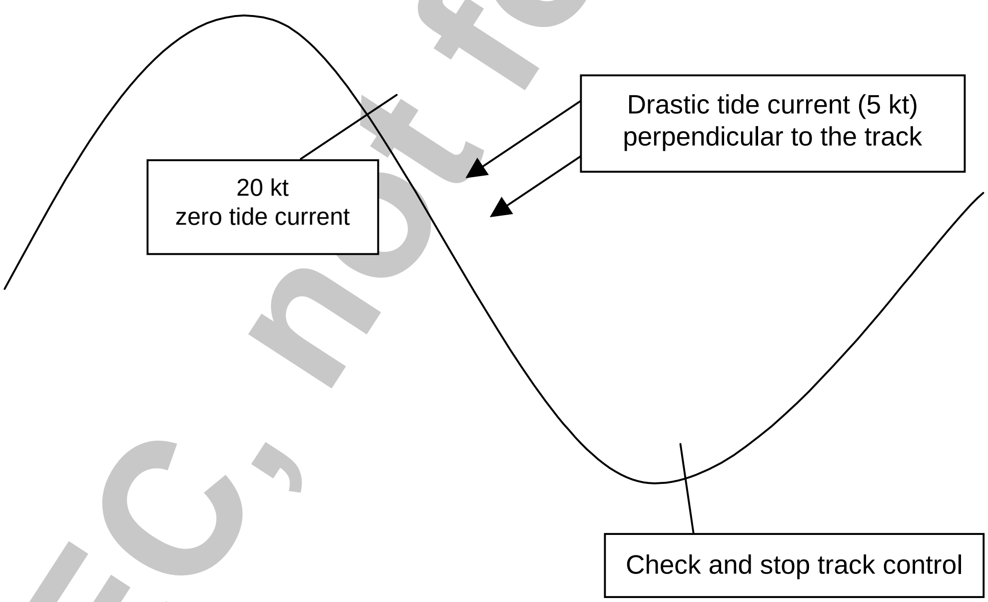
Explanation of adaptation tests (5.3.3.1)

The following graphs indicate where events are to be introduced into scenario 3 for the testing of adaptation.

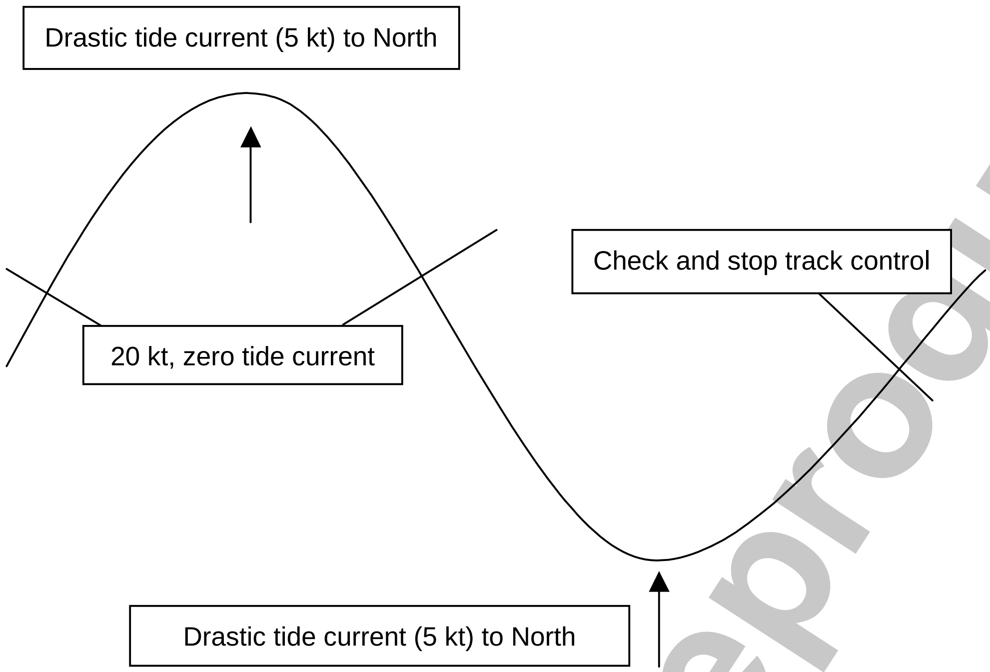
J.1 Adaptation to speed change



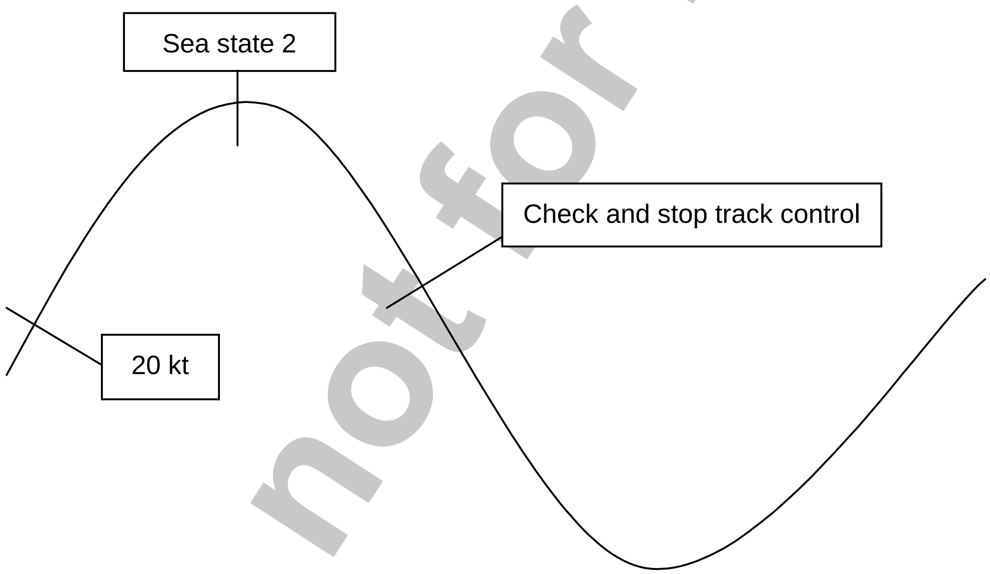
J.2 Adaptation to tide current changes along straight leg



J.3 Adaptation to tide current changes during turn



J.4 Adaptation to sea state during turn



J.5 Adaptation to sea state change on straight leg